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RESULTS OF A FEASIBILITY STUDY ON SENSOR DATA FUSION FOR THE CP-140 AURORA MARITIME PATROL AIRCRAFT

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February / février 1996

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19/1/96
Date

SANS CLASSIFICATION

ABSTRACT

This report presents the final results of a study on the feasibility and usefulness of data fusion for the CP-140 Aurora maritime patrol aircraft. Relevant sensor fusion concepts and terminology have been defined along with a description of the CP-140 operational environment and information sources. An analysis of applicable sensor fusion processes is presented followed by a discussion on the expected performance improvements. Finally, a three step incremental approach is proposed with recoverable steps where different level of fusion sophistication can be implemented based on the availability of the technology and the actual status of the sensors on the aircraft.

RÉSUMÉ

Ce document présente les résultats d`une étude de faisabilité visant à porter la fusion de données à bord de l`avion de surveillance maritime Aurora CP-140. En premier lieu, les concepts et la terminologie relatifs à la fusion de données sont clairement définis ainsi que l`environnement opérationnel du CP-140 et les sources d`information disponibles. Une analyse de certains concepts de fusion de données applicables au CP-140 est ensuite présentée suivie d`une brève discussion sur les éventuels bénéfices. Finalement, une approche en trois étapes est proposée pour l`implantation des niveaux de sophistication de fusion. Ces étapes dépendent grandement de l`état actuel des capteurs du CP-140 et de la disponibilité de la technologie sur la fusion.

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EXECUTIVE SUMMARY

The CP-140 aircraft will undergo a Life Extension (LE) program that could replace a number of sensors as well as the General Purpose Digital Computer that provides command, control, and data management of the sensors. The CP-140 Statement of Requirement (SOR) has identified "data fusion" as an essential requirement for the CP-140. This report presents the results of a feasibility study to implement data fusion aboard the CP-140.

More precisely, this document describes how to provide automatic target tracking and identification through Multi-Sensor Data Fusion onboard the CP-140. Relevant sensor fusion concepts and terminology are defined along with a description of the CP-140 operational environment and information sources. As a result of the analysis of applicable sensor fusion processes, a hybrid sensor data fusion architecture is proposed for the CP-140.

For the tracking aspect, the radar, the IFF, and the FLIR all have good resolution and accuracy and hence are ideal for central-level fusion. The ESM sensor has very poor resolution and accuracy in the one dimension (bearing) it measures. Therefore the sensor-level fusion approach is selected in this case in order to allow an ESM track to first develop so that better data is available for the subsequent correlation process. The remaining sensors, Link 11 and acoustic sensors are suitable for sensor-level fusion since their outputs are already in track form and not in contact form.

For the identification aspect, a central-level fusion architecture is recommended to ultimately declare an ID from the fusion of the raw target features extracted by the SAR and FLIR sensors. For the identity information provided by the other sensors (ESM, IFF, Acoustics) or by non-organic sources (Link 11) already offering identity declarations as their output data, the sensor-level architecture is an appropriate approach. This architecture can be adapted to include identity declarations inferred by operators as well as the ones deduced by non-organic systems.

Since the types of data processed and the time scales involved are so different between the under water sensors and the above water sensors, two distinct data fusion centres are recommended with a common track data base that insures the required communication between the fusion centres. Finally, a three step incremental approach is proposed for the implementation with recoverable steps where different level of fusion sophistication can be implemented based on the availability of the technology and the actual status of the sensors on the aircraft. The results presented in this report will be used to derive reasonable and prioritized requirements for the CP-140. The report will be provided as reference documentation to the CP-140 Life Extension definition contractor as supporting data. The definition contractor will then make its proposal for implementation.

LIST OF ACRONYMS

AAM	Air-to-Air Missile
ADP	Acoustic Data Processor
AIFIE	Attribute Information Fusion for Identity Estimation
ALE	Aurora Life Extension
ALEP	ALE Program
AOP	Area of Probability
ASM	Air-to-Surface Missile
ASO	Acoustic Sensors Operator
ASW	Anti-Submarine Warfare
ASuW	Anti-Surface Warfare
AWACS	Airborne Warning And Control System
CCS	Command and Control System
CFB	Canadian Force Base
CPF	Canadian Patrol Frigate
CPU	Central Processing Unit
CR	Cross-Range
DFO	Department of Fisheries and Ocean
DGPS	Differentiated GPS
DIAC	Data Interpretation and Analysis Center
DICASS	DIrectional Command Activated Sonobuoy System
DIFAR	DIrectional Frequency Analysis and Recording
DM	Data Mile
DND	Department of National Defense
DoD	Department of Defense
DREV	Defense Research Establishment Valcartier
EO	Electro-Optics
ESM	Electronic Support Measures
FLIR	Forward Looking Infra-Red
GPS	Global Positioning System
GSG	Government Systems Group
Hz	Hertz (cycles per second)
ID	IDentification
IFF	Interrogation Friend or Foe
INS	Inertial Navigation System
IR	Infra-Red
IRST	Infra-Red Search and Track
ISAR	Inverse SAR
LLLTV	Low Light Level TV
LOFAR	LOw Frequency Analysis and Recording
LRR	Long Range Radar

MAD	Magnetic Anomaly Detector
MHT	Multiple Hypothesis Tracking
MPD	Multi-Purpose Display
MRR	Medium Range Radar
MSDF	Multi-Sensor Data Fusion
NASO	Non-Acoustic Sensors Operator
NATO	North Atlantic Treaty Organization
NAVCOM	NAVigation/COMmunication operator
NILE	NATO Improved Link Eleven
OMI	Operator Machine Interface
PPI	Plan Position Indicator
PRF	Pulse Repetition Frequency
RAASP	Replacement Aurora Acoustic Signal Processor
RDP	Range-Doppler Profile
RPM	Revolutions Per Minute
SAR	Synthetic Aperture Radar
SARSAT	Search And Rescue SATellite
SHINPADS	SHipboard Integrated Processing and Display System
SR	Sonobuoy Receiver
SRS	Sonobuoy Reference System
SSAR	Spotlight Synthetic Aperture Radar
SSC	Supply and Services Canada
TACNAV	TACtical/NAVigation operator
TDS	Tactical Display Station
UN	United Nations

1.0 INTRODUCTION

The CP-140 aircraft will undergo a Life Extension (LE) program that could replace a number of sensors. The project could also replace the General Purpose Digital Computer (GPDC) that provides command, control, and data management of the sensors. Given these considerations, Multi-Sensor Data Fusion (MSDF) has been identified as a technology that could greatly enhance the tactical crew abilities to perform their missions. The Data Fusion and Resource Management Group at Defence Research Establishment Valcartier (DREV) has been involved for many years in the analysis, development, implementation and evaluation of MSDF algorithms and techniques for the automation of the target tracking and identification processes on a Canadian Patrol Frigate (CPF) ship. Much work in MSDF has also been carried out for the CPF program by Unisys GSG (now Loral Canada) (most of the time contracted by DREV, or by DND with DREV as scientific advisor) and there is a possibility to use some of that technology for the CP-140 aircraft. Another potential candidate for data fusion technology expertise resides at Westinghouse Norden Systems (Melville, NY) who developed a family of Integrated Automatic Detection and Tracking (IADT) systems that are currrently deployed on cruisers, destroyers, frigates, and amphibious assault ships in the US and foreign navies.

In that context, DREV has been tasked by DGAEM/DMAEM with PMO Aurora as Project Officer to investigate the feasibility of migrating the shipboard MSDF technology discussed above to the airborne domain. A contract was awarded to Loral Canada to study the possibility of using some of the data fusion technology developed for the CPF in the CP-140 context. A similar contract was awarded to Westinghouse Norden Systems to study the applicability of the IADT systems developed for the US and foreign navies to an airborne platform. Following these efforts, DREV has analyzed and evaluated the conclusions and proposed implementation approach of each of the contractors. Based on these results and on DREV expertise in the MSDF domain, this report presents the final results on the feasibility and usefulness of an MSDF implementation for the CP-140.

Defence Research Establishments, both in Ottawa (DREO) and Atlantic (DREA), have been consulted as relevant sources of specialized expertise in sensors (radar, ESM, acoustics).

This study addresses the analysis and evaluation of data fusion algorithms appropriate for target kinematics (i.e. position, speed, etc.) and non-kinematics (i.e. shape, type, identity, etc.) data obtained from the CP-140 multiple and dissimilar sensor sources (e.g., radar, Electronic Support Measures (ESM), Magnetic Anomaly Detector (MAD), sonobuoys, Forward Looking Infra-Red (FLIR), Synthetic Aperture Radar (SAR), etc.), and other information available on-board the CP-140 aircraft, within its operational and tactical environments, and environmental conditions. It is very important to stress that the scope of this study is limited to feasibility rather than detailed design.

Relevant sensor fusion concepts and terminology are defined in Chapter 2 of this report, followed in Chapter 3 by a definition of the CP-140 operational environment. Chapter 4 describes the CP-140 information sources. A description of applicable sensor fusion processes appears in Chapter 5. Expected performance improvements resulting from data fusion are discussed in Chapter 6, and an implementation plan is proposed in Chapter 7.

The research and development activities described in this document were performed at DREV between 1994 and 1995 under PSC32D58.

2.0 SENSOR DATA FUSION CONCEPTS AND TERMINOLOGY

Throughout the 1980s, the three U.S. military services pursued the development of tactical and strategic surveillance systems employing data fusion and supported extensive research in the areas of target tracking, target identification, algorithm development for correlation (association) and classification, and the application of intelligent systems to situation assessment (Ref. 1). The large amount of fusion-related work in this period raised some concern over possible duplication of effort. As a result, the Joint Directors of U.S. Department of Defense (DoD) Laboratories (JDL) convened a Data Fusion Subpanel to (1) survey the activities across all services, (2) establish a forum for the exchange of research and technology, and (3) develop models, terminology and a taxonomy of the areas of research, development and operational systems.

As a result of many years of effort to establish standardization and stability in the lexicon of data fusion, the definition of many terms is slowly achieving consensus across the diversified application community (Ref. 2). Problem-specific nuances and shading in these definitions remain but agreement on a meaningful subset of terms does seem to exist, providing an important basis for communication across specialized research groups.

This chapter provides a definition of the basic terminology and concepts that are used throughout the rest of this report. Figure 1 while presenting the three types of MSDF architecture that are discussed in section 2.7, is used to illustrate the MSDF terminology and concepts.

2.1 Overall MSDF System

The overall tracking system (or MSDF system) comprises both a measurement (or sensing) component which provides observations of the target environment, and an estimation (or tracking) component (ranging from a simple software tracking filter to a sophisticated multi-target multi-sensor data fusion system) which:

1) acquires and maintains unambiguous, stable tracks corresponding to the perceived population of real objects within the volume of interest,
2) estimates the state and identity of each tracked object with the objective of keeping an accurate and complete awareness of the external environment, and
3) suppresses clutter and other unwanted objects (i.e., discards "uninteresting" targets from the scene).

The quality of the estimated picture (i.e., the output of the data processing function) should in principle be superior to that of the measured picture (i.e., the output of the signal processing function). As discussed in section 2.7, there is no particular requirement that the measurement and tracking components be collocated.

The remainder of this chapter discusses in details the various components of the overall MSDF system.

2.2 Environment

The ground truth picture represents the real composition and status of a scenario of tactical interest in the environment. It depicts the activities (i.e., position, kinematic behavior, emissions, and identity) of a number of real, distinct targets in a given area of interest. A target may be a plane, ship, missile, etc. Targets possess defined kinematic and non-kinematic properties. The trajectory of a target typically summarizes its kinematic properties. The target type or category, its allegiance, nationality, threat level and specific identification are examples of non-kinematic properties. The ground truth targets progress in time and space, defining a scenario that also includes the characteristics of the target emissions.

The MSDF system has to operate in the four-dimensional world of space and time. Typically, the commander of a military platform has to assess all the ongoing activities within a given space volume surrounding the platform. This volume is referred to as the

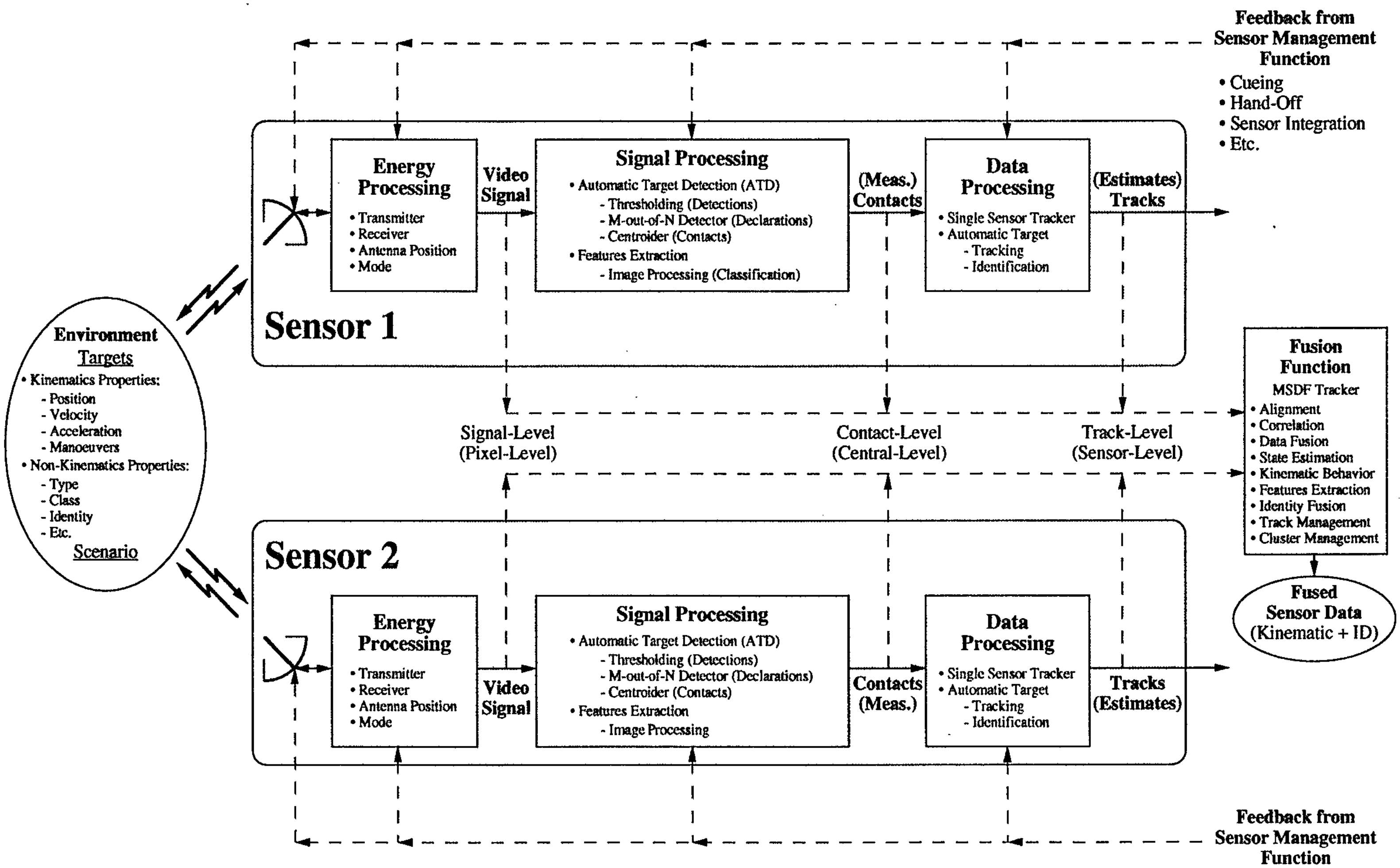

FIGURE 1 - Definition of three types of MSDF architecture (i.e., signal, contact and track-level) for two generic sensors

Volume Of Interest (VOI). For an MSDF system, it is defined by mission considerations, and there is no guarantee that the VOI will correspond to the MSDF system's sensor coverages. Since one is almost certainly concerned with a dynamic environment, one needs to take time into account as well.

Any realistic physical tracking environment also includes a number of unwanted objects of no immediate interest, e.g., sea surface, ground, mountains, birds, insects, clouds, rain and other meteorological phenomena, etc. These objects may cause returns that "clutter" the sensor display with false target declarations that may overload the processor elements and/or desensitize the sensor to the true targets. The important performance degradation effects potentially introduced by these unwanted objects must be taken into account by the sensor and MSDF designers.

2.3 Energy and Signal Processing (Detection and Measurement)

The measurement process encompasses both the energy and signal processing aspects. As part of signal processing, target detection is the process of determining the presence of a target, usually by declaring a target present if a voltage exceeds a threshold. Typically, military sensors generate detections that involve "point" targets (i.e., threshold crossings in only a few resolution cells), from which certain targets properties are measured. This is discussed in more depth below.

A sensor will typically spend a limited amount of time on a single target because, in most cases, scanning is necessary in order to provide updated information on established tracks and to search for new targets. One important sensor design consideration is the selection of a decision rule on the return received during the time on target, so as to discriminate between returns from targets of interest and returns from extraneous sources such as clutter. A widely spread approach to this decision process is to compare the incoming signal power to a threshold which is typically set so that the probability of false alarm remains constant. A "detection" occurs each time the received power exceeds the selected threshold.

For a given threshold setting, the probability of target detection will generally be a complex function of the sensor capabilities, the target size, the sensor-target geometry, and the physical environment (atmospheric attenuation, etc.). The threshold value should be selected taking into account its effect on overall tracking system performance. It may even be desirable to set the threshold adaptively.

Typically, it is assumed that the measurement set produced by a given sensor during a single scan contains at most one observation from each target which may be within the search volume of this sensor. This may require some redundancy elimination logic in the measurement preprocessing so that multiple simultaneous detections from the same source are combined. Typically, a sensor search volume may be covered using two or more bars in which the sensor scans in azimuth angle while maintaining a fixed elevation angle for each bar. In such a case, a redundancy elimination logic is required to ensure that detections received from the same target on multiple bars are not interpreted as being the result of multiple targets. The result of the centroiding of simultaneous detections to form a single report of a target is often called a "contact" (Fig. 1).

In addition to combining multiple detections from a single target, it is also desirable to recognize when a single observation was produced by multiple targets. For example, radar measurement techniques might not be able to resolve several closely spaced targets that are within the radar's beamwidth. However, radar data processing techniques have been developed to determine when there are multiple targets within the radar's beamwidth, even if distinct measurements from all targets cannot be obtained.

The term measurement usually refers to a physical observation of a parameter (i.e., a parameter plus noise). In the sensor data fusion domain, measurements are thus noise-corrupted observations related in a specified way to the state of a target. Measurement is a collective term that is used to refer to all the observed (or measured) quantities included in a raw report (or a contact) output from a sensor. A measurement differs from an estimate (or a track) because an estimate operates on multiple measurements over time to extract a more accurate assessment of the parameter.

Sensor measurement characteristics must be defined. This involves specifying measurable parameters, the accuracy associated with each measured parameter, and an update interval (or an adaptive update policy) for each sensor. In general, an observation may contain measured kinematic properties, such as position or Doppler (range rate), and measured non-kinematic properties (or attributes) such as target emitter type, radar cross section, allegiance, etc. An observation should also contain an estimate of the time at which the measurement was obtained (i.e., a valid time tag). Measurement accuracies are typically specified as error variances or covariances. In general, observations may be received at regular intervals of time (scans or data frames), or they may occur irregularly in time.

A "clean" measurement is of the highest quality; it corresponds to a single object of interest in the environment. Typically however, as a result of the many perturbing factors discussed in section 2.9, the measured tactical picture is not composed of solely clean measurements. A sensor can observe a region containing an object but fail to detect it (i.e., object detection is not guaranteed (probability of detection < 1)), whether or not it is being tracked. Such undetected targets correspond to "missed" measurements. Sensor measurement techniques might not be able to determine when there are several closely spaced targets within the sensor's beamwidth. In such a situation, distinct measurements from all targets cannot be obtained, and a single observation is typically produced by the multiple targets. The measurement produced by unresolved closely spaced objects is often called a "merged" measurement or a "clump". Finally, some "spurious" measurements (or spurious threshold crossings) are due to noise alone (i.e., false alarms), or due to non-zero-mean interference with unknown spatial and temporal covariance (i.e., clutter). These spurious contacts can be misclassified later by the estimation process as being from an object of interest.

2.4 Sensor-Level Data Processing (Tracking and Identification)

The perception of the ground truth tactical picture by the sensor-level data processing system is embodied in the estimates (or tracks) that are established or continued as the sensor samples the environment over some time interval of interest. For each target in the environment, the system attempts to maintain estimates of its location, velocity and acceleration, and several types of attribute and identity estimates.

Estimation is the process of inferring, in some optimal fashion, the value of a parameter of interest from indirect and inaccurate measurements (reported as contacts) related in a specified way to this parameter. In other words, an optimal estimator is a computational algorithm that processes noisy measurements to obtain a "best estimate" (minimum error in some sense) of a given parameter (or set of parameters) of interest. This parameter can be:

- a time-invariant quantity (a scalar or a vector),
- the state of a dynamic system (usually a vector).

In principle, the estimate should be a more accurate assessment of the parameter than the raw measurements. However, this is not always the case. The achievement of an estimate of the state of a dynamic system utilizes a priori information (or static inputs) such as:

- knowledge of system and measurement dynamics,
- assumed statistics of system noises and measurement errors,
- initial conditions,

so that optimal estimators are sensitive to erroneous a priori models and statistics.

Target state estimation (the heart of any tracking system) is the processing of noisy contact data, hypothesized as arising from the same object or target, in order to maintain an estimate of its current state which typically consists of kinematic components. State estimation may consist of filtering (estimating the properties at the time of the latest observation), smoothing (estimating the properties at a time in the past using all the measurements available up to the latest observation), and prediction (estimating the properties at a time in the future).

The target identification aspect also needs to be considered in order to produce the complete tactical picture. The estimation process must accurately integrate the distinguishing attributes of the targets actually observed, and provide estimates of their identification.

Strictly speaking, a track is thus assumed to be a triple comprising:

1) One or more state vectors estimating the kinematic properties (i.e., position, course and speed, acceleration, etc.) of the target, with a covariance matrix for each state vector. If more than one state vector is used, the relative likelihood (or weight) of each one is also included.
2) One or more propositions about non-kinematic properties (target type, class, identity, radar cross-section, IR signature, etc.) of the target, each with its associated likelihood function.
3) The probability of the track. It is the data processing algorithm's estimate of the absolute likelihood that the track exists (i.e., actually corresponds to some ground truth target).

In practice however, the information kept in a track file also includes many other parameters such as the ones listed in TABLE I below.

A "clean", stable track is of the highest quality; it corresponds to a single object of interest in the environment over the track's entire history, without any pathologies such as misassociation (except, perhaps, during its initialization stage, when some bit of "bouncing around" may occur) or premature loss of track. Spurious tracks include "redundant" (i.e., more than one track for one target), "false" (i.e., tracks for no targets whatsoever), and "lost" tracks. "Missed" tracks are targets without tracks.

In the typical scenarios we are interested in, there can be anywhere from a few to hundreds of targets to follow. The tracking system must accurately indicate the correct number of targets present. It is important that the tracker strikes a balance between too many (false) and too few (missed faint but real targets) tracks.

TABLE I

Typical track information maintained in a track database

Parameter Type	Example
Indexing Parameters (Book Keeping)	track number, cluster number, track status (i.e., potential, tentative or firm), etc.
Timing Information	time of the current estimate, last update time, etc.
Quality Parameters	quality index, score, etc.
Update History Information	last updates (contacts or tracks) vector, hit/miss pattern (blip/scan information), etc.
Matching History Information	similarity with other tracks, etc.
Data Association Information	validation matrix, type of gating, etc.
Kinematic Information	state vector and its covariance matrix
Identity Information (Attributes)	target size, shape, degree of symmetry, etc. and their confidence values
Identity Information (ID Declarations)	threat category, classification, category, description, type, class, unit, etc. and their confidence values

2.5 Data Fusion Definition

Data fusion is fundamentally a process designed to manage (i.e., organize, combine and interpret) data and information, obtained from a variety of sources, that may be required at any time by operators and commanders for decision support. The sources of information may be quite diverse, including sensor observations, data regarding capability and availability of targets, topographic and environmental data, and information regarding doctrine and policy. The data and information provided by these various sources may contain numbers of targets, conflicting reports, cluttered backgrounds, degrees of error, deception, and ambiguities about events or behaviors.

In this context, Data Fusion (DF) is an adaptive information process that continuously transforms the available data and information into richer information, through continuous refinement of hypotheses or inferences about real-world events, to achieve refined (and potentially optimal) kinematic and identity estimates of individual objects, and complete and timely assessments of current and potential future situations and threats (i.e., contextual reasoning), and their significance in the context of operational settings.

The process is also characterized by continuous refinements of its estimates and assessments, and by evaluation of the need for additional data and information sources, or modification of the process itself, to achieve improved results.

2.6 Data Fusion Hierarchy

The process of data fusion may be viewed as a multi-level hierarchical inference process whose ultimate goal is to assess a mission situation and identify, localize and analyze threats. However, not every data fusion application is responsible for all of these outputs. Some applications are only concerned with the position and identification of objects. Other applications are primarily oriented towards the situation and how it is evolving. Still others focus on the threat and its possible impacts upon achieving mission objectives. In addition, the data fusion function can be responsible for identifying what information is most needed to enhance its products and what sources are most likely to deliver this needed information.

Given these considerations, a complete data fusion system can typically be decomposed into four levels:

Level 1 - Multi-Sensor Data Fusion (MSDF);
Level 2 - Situation Assessment (SA);

Level 3 - Threat Assessment (TA); and,

Level 4 - Process Refinement Through Resource Management (RM).

Each succeeding level of data fusion processing deals with a greater level of abstraction. Level-1 data fusion uses mostly numerical, statistical analysis methods, while level-2, 3 and 4 data fusion use mostly symbolic, Artificial Intelligence (AI) methods. Note that resource management in the context of level-4 fusion is mainly concerned with the information gathering process refinement (i.e., sensor management). The overall domain of resource management also encompass the management of weapon systems.

2.6.1 Level 1 - Multi-Sensor Data Fusion

Multi-sensor data fusion (MSDF) is concerned solely with individual objects, first in associating the sensor outputs with specific known objects or using them to initiate new objects. Level-1 processing uses sensor data to correctly and quickly derive the best estimates of current and future positions for each hypothesized object. In addition, inferences as to the identity of the objects and key attributes of the objects are developed.

Key MSDF functions include: data alignment, data association or correlation, kinematic data fusion, target state estimation, target kinematics behaviour assessment, target identity information fusion and the management of clusters and tracks.

In any MSDF system, sensor data alignment in time and space must take place before state estimation can be performed. Moreover, in order to estimate and remove the effects of sensor motion from the received data, various Inertial Navigation Systems (INS) are used, involving a wide variety of motion sensors including gyroscopes, accelerometers, and the Global Positioning System (GPS) (Ref. 3). The motion corrected observations are processed to form tracks.

The functions of data association (labeling measurements from different origins and/or sensors, at different times, that correspond to the same object or feature) and data fusion (combining measurements from different times and/or different sensors) are also required in one form or another in essentially all multiple sensor fusion applications: one function determines what information should be fused, the other function performs the fusion (Ref. 3).

2.6.2 Level 2 - Situation Assessment

Based on incomplete and inaccurate sets of data and information, situation assessment (SA) is devoted to the continuous inference of statements about the hypothesized objects provided by the lower level data fusion function in order to derive a coherent, composite tactical picture of the situation. This picture must be described in terms of groups or organizations of objects so that enemy intent can be estimated in the next level and decisions can be made by decision makers about how to use war fighting assets.

Hence, SA fits hypothesized objects with known and expected organizations and events, together within the constraints of terrain and enemy tactics, to develop a description or interpretation of the current relationships among these objects and events in the context of the operational environment. The result of this processing is a determination or refinement of the battle/operational situations. Based on the situation abstraction products and information from technical and doctrinal databases, SA also attempts to anticipate future events over a short time horizon. Key SA functions include: object aggregation, event/activity aggregation, contextual interpretation/fusion and multi-perspective assessment.

2.6.3 Level 3 - Threat Assessment

Threat assessment (TA) is focused at the details necessary for decision makers to reach conclusions about how to position and commit the friendly forces.

By coupling the products of situation assessment with the information provided by a variety of technical and doctrinal databases, TA develops and interprets a threat oriented perspective of the data to estimate the enemy capabilities and lethality, identify threat opportunities in terms of the ability of own force to engage the enemy effectively, estimate enemy intent (i.e., provide indications and warnings of enemy intentions), and determine levels of risk and danger.

Hence, TA uses the situation picture from level 2 and what is known about the enemy doctrine and objectives to predict the strengths and vulnerabilities for the threat forces and friendly forces. In addition, the friendly mission and specific options available to the decision makers are tested within these strengths and vulnerabilities to guide decision making.

Key TA functions include: enemy forces capability estimation, predict enemy intent, identify threat opportunities, multi-perspective assessment and offensive/defensive analysis.

2.6.4 Level 4 - Process Refinement (Sensor Management)

Information resource management, level 4 processing, closes the loop by first examining and prioritizing what is unknown in the context of the situation and threat and then developing options for collecting this information by cueing the appropriate sensors and collection sources.

2.7 Multi-Sensor Data Fusion Architectures

Before an MSDF function can be implemented within a military platform, it must be analyzed in terms of the different types of architecture and implementations that are possible, the benefits and drawbacks of these implementations, and finally in terms of how all this relates to the performance and mission requirements of the platform (Ref. 4).

For any given sensor suite configuration, there can be many different ways to combine data from the sensors. The term "MSDF architecture" is used to indicate, based on the level at which the sensor data are fused (i.e., signal, contact or track level), the general method (or philosophy) used to combine the sensor data into global tracks within an MSDF function.

Figure 1 illustrates on a single diagram the usual definition of three types of MSDF architecture for two generic sensors. One possible type of MSDF architecture is based on maintaining sensor-level tracks at each sensor site, finding the sensor tracks that potentially represent the same target and then combining these tracks into global tracks of the MSDF function. A second type of architecture assumes that the raw sensor measurements (i.e., sensor contacts) are sent directly to the MSDF function to be combined into global tracks. This architecture is sometimes referred to as a "central-level" architecture since the tracks are only formed into the central processor. As a third type, fusion at the signal-level typically combines signals from similar sensors to produce a better quality signal of the same form. Finally, there is also the possibility of using a mixture of these three types of architecture to form a hybrid (or combined) tracking structure.

The MSDF architecture is an important issue since the benefits are different depending on the way the sensor data are combined. The selection of the MSDF architecture type should be aimed at optimizing the target detection, tracking and identification performance required for a specific platform given its missions. However, the selection is also constrained by the technological capabilities (both hardware and software). It depends on the quality of the sensors being fused, the availability of computer processing power, the bandwidth of the available data transmission paths, and the degree to which operator intervention is required or desired (see Refs. 5-6). Table II below, extracted from Ref. 7, lists the main advantages of the central-level architecture.

TABLE II
Advantages of the central-level fusion architecture

Advantage	Reason
Quick Reaction Time	All sensors which detect a target will be used to initiate track on the target.
Optimum Track Accuracy	Each track contains more data per unit time. Data from one sensor may be used to augment data from another sensor.
Good Track Continuity	Each track contains more data per unit time. Also one sensor may be blocked while another has contact with the target being tracked.
Good Track Resolution	Sensors have different resolving abilities. The angle resolution of a FLIR is 10 times as good as a radar.
Good False Track Suppression	The data from each sensor is used immediately to confirm target maneuvers before track is lost or corrupted.

The **disadvantages** of central-level fusion are that it requires a large amount of computer processing power, a relatively high bandwidth for transmitting contact data from the sensor to the central site for fusion, and it must be possible to correlate the sensor data to the track data on a scan-to-scan basis.

The **advantages** and **disadvantages** of sensor-level fusion are the mirror image of the contact-level fusion discussed above. This approach requires less processing power in the central data fusion site and requires less I/O bandwidth to transmit the data between the sensor and the central site. Table III below, also extracted from Ref. 7, lists the main disadvantages of the central-level architecture.

TABLE III

Disadvantages of the sensor-level fusion architecture

Disadvantage	Reason
Poor Reaction Time	A track is detected only after a single sensor has promoted the track to firm
Poor Track Accuracy	If track selection fusion is used then single sensor tracks will not have the accuracy of multiple sensor tracks. If track fusion is used then target maneuvers become difficult to follow.
Poor Track Continuity	Track selection fusion can lead to jittery (unsmooth) track data while track fusion may cause a break in track during target maneuvers.
Poor Track Resolution	It is very likely that a track which is resolved on one sensor and not on another will appear as two or three tracks in this type of fusion.
Poor False Track Suppression	Poor track to track correlation will inevitably lead to multiple tracks on the same target.

2.8 Sensor Management

In the traditional elaboration, MSDF is portrayed as a purely passive, open loop process (i.e., a function that simply processes whatever it receives). In the more advanced and enlarged sense however, an MSDF system also includes many additional functions, the most essential of which is active feedback. An MSDF system not only detects, localizes, and identifies targets, but also, on the basis of an evolving picture, manages the information it might receive by pointing, focusing, manoeuvering, and adaptively selecting the modalities of its sensors and sensor platforms (Ref. 8).

In order to maximize target information and fire support obtained by sensors while minimizing the threat to system and assets (e.g., through an emission control (EMCON) policy), sensor management is a decision process which addresses the following questions:

- When to search, track, remain covert?
- What regions to search, what objects to track?
- How long to search, track, remain covert?
- With which sensor combinations? Fire support?

Sensor management is thus a resource allocation problem. Sensor cueing, hand-off and scheduling issues are part of the sensor management domain.

The management of sensors may require that different sensors cooperate to acquire measurements on a common target. The two primary cooperative functions are cueing and hand-off. *Cueing* is the process of using the detections (i.e., contact-level cueing) or tracks (i.e., track-level cueing) from one sensor (A) to point another sensor (B) toward the same target or event. *Hand-off* occurs when sensor A has cued sensor B for transferring surveillance or fire control responsibility from A to B.

Two processes must occur for cueing or hand-off: (1) the cueing sensor must provide the cued sensor data that contains sufficient information to point to the target and identify it as the specific target being cued, (2) the cued sensor must search for the target of interest and verify that it has been acquired.

Another issue related to active feedback is sensor integration which involves the modification of the sensor design so that it can receive and use pertinent information from other sensors or from the Command and Control process, to improve or refine its own performance. In other words, sensor integration allows the sensor to do its task better than as a stand alone autonomous sensor. Sensor integration is to a large extent a sensor system designer's issue.

In summary, an advanced MSDF system indicates what the targets are, where they are, where they aren't, and where it hasn't looked (Ref. 8). In this regard, sensors and sensor platforms are selectively employed to:

- look for, and find targets within a specified volume of interest (this implies that one demarcates the VOI, and defines search strategies for achieving the best possible sensor coverage),
- enhance accuracy (by point and dwell) against priority targets,
- increase detections (by more frequent visits) in interesting or threatening regions,
- balance these objectives in accordance with the mission declaration, and
- operate its sensors within power, time, mutual interference, and EMCON constraints.

In practice, most current-day MSDF systems achieve feedback through the agency of operators equipped with tactical decision aids. These functions can be called "Value/Cost Analysis, Decision and Command". With the introduction of next-generation sensors, characterized by receiver-transmitter agility, abundant modalities, and multifarious constraints, automation of the sensor management and integration loop will become a virtual necessity (Ref. 8).

2.9 Limitation Factors

The observations (i.e., the contacts) generated by the energy and signal processing processes and passed to the tracker are affected by the characteristics of: the targets of interest, other objects in the field of view, background clutter, environmental phenomena between sensor and objects/background, sensor location relative to the objects and background, design of the sensors and signal processor algorithms, etc. The measurements may also be distorted by sensor pointing and location (navigation) errors. The resulting measurement vectors thus reflect feature inferencing errors, kinematic measurement errors that typically are not Gaussian, false and missing observations, impact of background clutter, unresolved closely spaced objects, etc.

A number of uncertainties also affects the data processing function (i.e., the estimation process). Target state estimation algorithms typically use some practical models of target motion in order to estimate the present and future target kinematic quantities. These target kinematic models are generally simple (such as straight line paths, circles, etc.) and assumed to be described by well known physical laws (e.g., ballistic laws, etc.). Unexpected changes to these assumed target motion models (i.e., "random" acceleration) are called manoeuvers. Any mismatch, during a manoeuver, between the real kinematic behavior of a target and the motion model assumed by a simple target state estimation algorithm can completely degrade the performance of the estimation technique. For example, in addition to the development of a track bias, some measurements actually from an object of interest can be misclassified as being from a different object, or as being noise or clutter.

2.10 Automation Issues

The issues of interest for the CP-140 are target detection, tracking and identification. Indeed, accurately detecting, locating and identifying potential targets is fundamental for the success of the mission of the aircraft. Given the diversity of the many sensors onboard the CP-140, data fusion is mandatory as a means to exploit the unique combinations of data that is available. In view of these considerations, a major aspect that needs to be addressed is the issue of manual operations versus automation. Figure 2 illustrates the interrelationships between these various concepts related to sensor data fusion.

Currently, target detection, tracking and identification are performed manually by the operators onboard the aircraft. Sensor data fusion is also performed manually. The scope of the feasibility study discussed in this report is the automation of all these aspects. However, the optimal upgrade path from the current system (where everything is manual) to the ultimate automated system (including automated MSDF) is far from being trivial. Chapter 7 presents the incremental approach (with recoverable steps) recommended by DREV to implement sensor data fusion on the CP-140.

Before any of the detection, tracking and identification processes can be automated, the video signal from the sensor must be digitized. This is a formality. It has no impact on operator efficiency or mission effectiveness.

Then, one may automate the target detection process for one or more sensors individually. This could improve mission effectiveness. However, in order to be able to detect very small targets at long range, the detection process would have to be allowed to generate many false alarms. This could provide additional load on the operator to manually manage all these detections (true and false), thus impacting the operator efficiency.

A solution to this problem could be to also automate the tracking and identification process at the sensor level (i.e., for each sensor individually). However, the development and/or acquisition of such better but stand-alone sensors used in isolation from each other typically leads to a confusing and time-late decision environment. The operators might be flooded by the volume, rate and complexity of the information provided by these sensors to a point where their ability to cope with that information may be exceeded, thus also impacting the operator efficiency.

A key element to this information management problem is the ability to automatically combine or fuse data from the sensors. This is the optimal way to do automatic target detection, tracking and identification when multiple sensors are available. One might first do automatic detection, tracking and identification with each single sensor individually and then do sensor fusion. However, as previously discussed in section 2.7, this is not the optimal way of doing automation for a multiple sensor system since one limits the fusion to be at the track level (as opposed to fusion at contact level which is the optimal approach). The optimal upgrade path is rather to automate the individual sensors up to a certain level (say, automatic target detection), and then to automate the tracking and identification processes based on a central-level MSDF architecture. Chapter 7 discusses these issues in more depth, and presents the recommended approach.

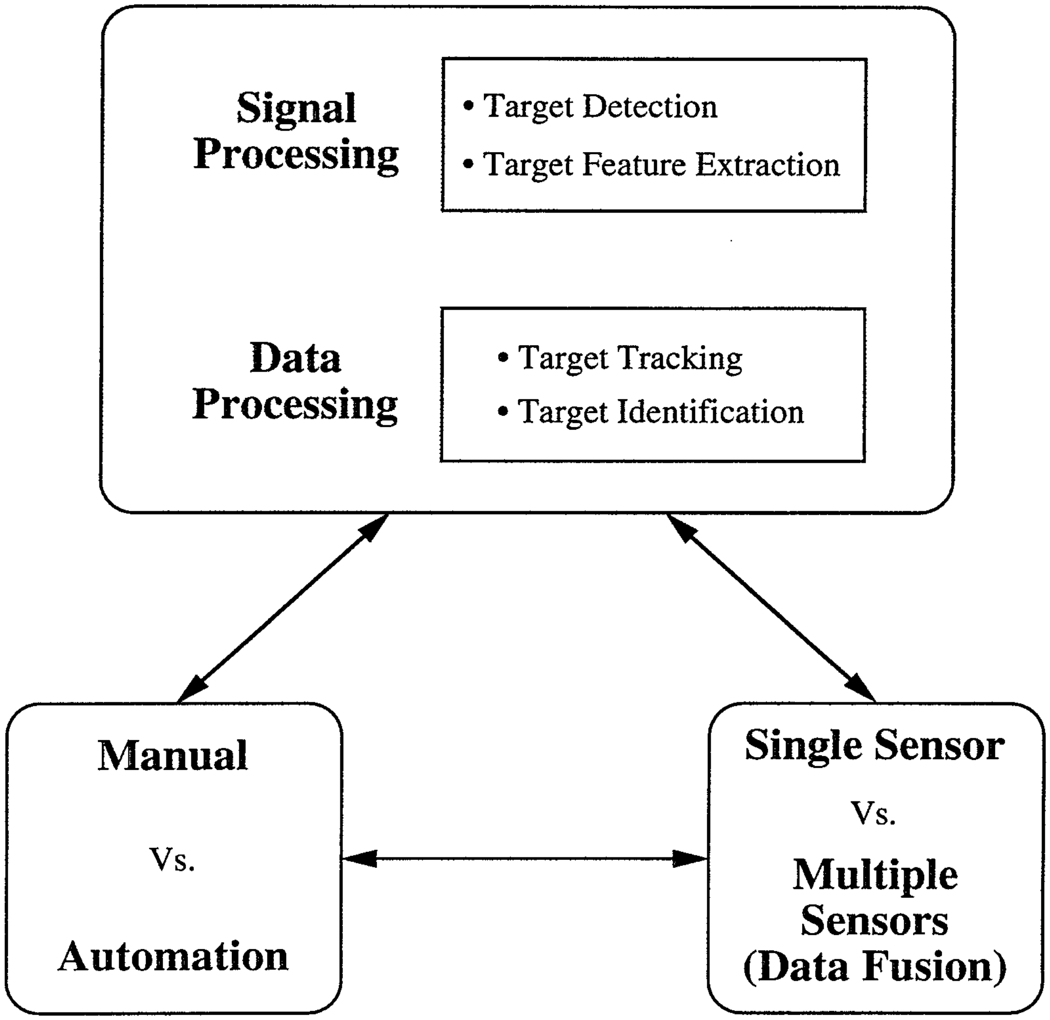

FIGURE 2 - Interrelationships between the various concepts related to sensor data fusion

3.0 DEFINITION OF THE CP-140 OPERATIONAL ENVIRONMENT

This Chapter summarizes from Ref. 9 the CP-140 operational environment in terms of mission requirements (e.g., ASW, surface surveillance, target tracking, goals, etc.) and tactical scenarios (targets, environmental conditions,etc.). Loral Canada has identified from Ref. 10 the missions to which MSDF techniques could be applied to advantage. Details on the missions are in Refs. 9-10; here we only present the essential information for the sake of the feasibility study.

3.1 Mission Requirements

The mission of Air Command is to maintain balanced, general purpose, combat capable air forces to meet Canada's defence policy objectives. In supporting these objectives, the Aurora is called upon to perform various mission elements, each of which is supported through the performance of associated tasks, which collectively account for the major General Purpose Air Forces (GPAF) activities. Using the nomenclature of the GPAF, Loral Canada has identified the following mission elements relevant to the CP-140:

a. A3 - Maritime Defence

b. A6 - Domestic Air Support;

c. A7 - Collective Defence of the North Atlantic;

d. A8 - Maintenance of International Peace

e. A9 - Support of Canadian Interests Abroad

f. A12 - Collective and Individual Training

In fulfilling its assigned missions, in both peacetime and wartime, the Aurora is called upon to perform those tasks defined in Table IV. A detailed description of those tasks can be found in Ref. 9.

TABLE IV

Aurora mission elements and associated tasks according to the GPAF

MISSION	TASKS
A3 - Maritime Defence	AC 3 - Maritime Area Operations AC 4 - Maritime Direct Support
A6 - Domestic Air Support	AC 11 - Search and Rescue AC 15 - Counter Drug AC 16 - Maritime Patrols AC 17 - Northern Patrols AC 19 - Domestic Contingency
A7 - Collective Defence of the North Atlantic	AC 21 - NATO Maritime Operations
A8 - Maintenance of International Peace	AC 24 - Air Continental Operations AC 25 - Joint Maritime Air Continental Operations AC 28 - Air Surveillance
A9 - Support of Canadian Interests Abroad	AC 24 - Air Continental Operations AC 25 - Joint maritime Air Continental Operations AC 28 - Air Surveillance
A12 - Collective and Individual Training	AC 34 - Operational Training Unit Training

3.2 Tactical Scenarios

Given the varied nature of the present and planned Aurora tasking, it is impossible to define a set of mission scenarios which will describe all possible tasking. However, based upon those defined in the Marconi Human Factors Engineering Study (Ref.10), the following set of scenarios is considered for the purpose of this study:

a. conduct nuclear submarine asw;

b. conduct diesel-electric submarine asw;

c. join task force;

d. conduct over-the-horizon targeting and damage assessment;

e. conduct search and rescue;
f. shadow a surface vessel suspected of smuggling;
g. conduct fishing and pollution surveillance, and,
h. conduct northern patrol

TABLE V

List of missions/tasks/scenarios with expected targets and information

Mission /Task /Scenario	**Expected Targets**	**Information Sources**
Fisheries Patrol	Medium sized boats, trawlers	Radar, SSAR, FLIR, camera
Drug Smuggling Patrol	Small speed boats, fishing boats, various sized ships	SSAR, radar, FLIR, camera, ESM, Link-11
Pollution Surveillance	Tankers, large ships, small boats	Radar, SSAR, FLIR, camera
Search and Rescue	Humans, dinghies, small boats, various sized ships	Radar, SSAR, ESM, FLIR, Link-11
Aircrew Training	All types	All sensors
ASuW	Large ships	SSAR, radar, FLIR, IFF, acoustics
Join Task Force	All types	All sensors
Air Surveillance	Air targets	IFF, ESM, FLIR, camera
ASW	Nuclear subs, diesel-electric subs	Acoustics, ESM, MAD, FLIR, radar

Loral Canada (Ref. 9) has used its airborne personnel's expertise to estimate the present frequency of occurrence of the various missions/tasks/scenarios. The purpose was not to re-prioritize the CP-140 missions but only to assess the benefits of data fusion against the most frequent missions. The missions/tasks/scenarios are shown, in decreasing frequency of occurence, in Table V where the targets that need to be detected, tracked and identified are listed by priority, for the purpose of this study only, together with the main information sources. The order becomes more arbitrary as one progresses further down the list. This order may change if the Aurora becomes more involved in international missions. It is apparent that when all surface vessels must be considered as possible threats and when the CP-140 aircraft's maritime surveillance missions take higher precedence, the role of sensors which can detect and provide attribute information about surface objects (e.g. SAR, FLIR and ESM) has to increase.

3.2.1 Environmental Conditions

The Aurora operates in every imaginable extreme of weather, from arctic winter conditions, during northern patrols, to conditions of high temperature and high humidity during deployed operations in the Caribbean and Southern Pacific regions. Since the majority of maritime patrol activity occurs over the North Atlantic and Northern Pacific Oceans, the weather normally encountered in these regions has a great impact on Aurora operations. In addition, the weather in the North Atlantic varies not only by season but by region.

Several special atmospheric conditions can adversely affect the received data. For non-acoustic sensors:

- rain and snow attenuate the radar beam due to *scattering* in both directions of propagation, while the phenomena have an impact on only one direction for the FLIR
- fog can mask surface targets from optical sensors
- atmospheric *refraction* can yield propagation ducts or propagation holes
- wind speeds in excess of 25 knots reduce the radar, FLIR and MAD's effectiveness
- shallow waters provide a rough bottom structure and composition that produce local variations of the earth's magnetic field, thus confusing the MAD

- sunspot activity can affect propagation and MAD

For acoustic sensors which are of concern mostly during the ASW mission, the list is equally imposing:

- natural *deep ocean* noises of geological or biological origin can provide a background that reduces sonobuoy effectiveness

- rain or turbulence produce *sea surface* background noise and surface traffic further confuses the ASOs

- rough seas can cause temporary antenna immersion and therefore an intermittent Sonobuoy Radio Frequency (RF) signal

- reverberation effects (surface, bottom or volume) cause unwanted underwater signals for active systems

- ocean currents can affect acoustic tactics, e.g. Gulf stream versus mid-ocean region etc.; currents cause drifts which have to be accounted for correct sonobuoy positioning and create acoustic walls

- shallow water ASW is particularly difficult.

3.2.2 Electromagnetic Environment

During peacetime, the Aurora generally operates overtly, communicating over open radio channels with Base Operations, Headquarters, Air Traffic Control and cooperating forces. Depending on the nature of the mission, the Aurora will likely participate in tactical data link with other surface and air forces, providing over-the-horizon targeting and receiving updated tactical information. During peacetime, full use will be made of all sensors, both active and passive, including extensive use of the radar to locate surface targets.

During wartime, the ability of the Aurora to openly communicate with friendly forces will be severely restricted by the requirement to limit detection through the enforcement of Emission Control (EMCON) conditions. Communications, when essential, will be encrypted and limited to the briefest possible duration. To prevent broadcasting its position, the Aurora will adopt a "receive only" posture, accepting radio communications, but not broadcasting an acknowledgment.

Sonobuoys will continue to be the major sensor for submarine detection and tracking during wartime. For the detection of surface targets, however, greater emphasis will be placed on the use of passive sensors, such as acoustics, Forward Looking Infrared (FLIR) and ESM, with radar emissions restricted to a single sweep in order to confirm target location prior to attack.

Depending on the field of operations and the nature of the enemy forces, the Aurora may be subjected to electromagnetic jamming in an attempt to confuse its communications and/or its radar and overload its passive sensors. Under such conditions, the jamming agent becomes highly visible in the electromagnetic spectrum, generally requiring extensive protection in order to remain on the air. For maritime patrols, it is most likely that the Aurora will encounter totally covert enemy forces as opposed to an active jamming environment.

4.0 CP-140 INFORMATION SOURCES

An analysis of the information sources for the CP-140 aircraft is presented in this chapter. The analysis covers the organic sensor information from the current sensor suite versus the information from an advanced suite of the same type of sensors, information available from additional sensors onboard the aircraft, and sensor information from other non-organic sources.

The investigation also contains an analysis of the current non-sensor technology for providing information to be used. Non-sensor technology is defined as all knowledge sources other than sensors, that can provide kinematic, identity or other information (e.g., data links, intelligence reports, environmental data, visual sightings (i.e., the "human eyeballs"), encyclopaedic data, etc.).

4.1 Review of the Current CP-140 Sensor Suite

Each sensor on board the CP-140 has to be described in terms of its potential contribution to the estimation of the state vector (kinematic and ID) of each target. This idealized contribution will be affected by the confronted tactical environment and the differing environmental conditions. A more specific definition of the information sources interface with the MSDF process is given in Chapter 5.

The following list (Table VI) is an account of the present sensors (in rough order of importance to fusion), with their measured kinematic and non-kinematic data (including measurements accuracy where applicable). The identity information that can be obtained through further processing is also provided in the list. The information is extracted from both Refs. 9 and 11. Here we retain only the essential information relevant to data fusion.

In Table VI below, the inputs to MSDF that are readily available from the sensor in its **current** version are listed in **bold**, while the other inputs can be made available through further processing, either in an improved version of the sensor, or in the data fusion function itself. The capability of post-flight analysis and subsequent update of the MSDF databases provided by the FLIR and camera exists but is not shown in the table.

TABLE VI

Present suite of sensors and their potential inputs to a data fusion function

Sensors	Input to MSDF	Accuracy (approximative)
1. Radar AN/APS-506	**range** **bearing**	0.45 m 0.24 °
2. ESM (ALR-502)	**bearing** **emitter ID** **threat number,** **AOP** platform ID	* The accuracy of the bearing and signal characteristics is classified. These numbers can be obtained from C-12-140-000/MB-z01 (p.4-36-1).
3. IFF AN/APX-502	**range** **bearing** **allegiance**	0.45 m 0.24 ° N/A
4. FLIR OR-5008/AA	**bearing** elevation target size and attitude platform ID	* Classified C-12-140-000/MB-z01 (p.4-37-1) * N/A N/A
5. Link-11	**Positions (tracks and also ID)**	* Accuracy is limited by by INS and GPS see [Ref.1], p.I-54.
6. ADP OL/5004/AYS	**Position** **Velocity** **ID**	Doppler together with bearing and time delay estimates can provide very accurate position course and speed estimates.
7. SRS AN/ARS-501	**Positions of up to 31 sonobuoys**	N/A
8. Camera	**Platform ID**	N/A
9. MAD	**Target position**	N/A

In Table VII, the current level of automation for each sensor is described along with some important characteristics. This is useful when estimating the level of effort to bring automatic target detection, tracking and identification (ATDTI) onboard the aircraft.

TABLE VII

Level of automation of the present suite of sensors

Sensors	Current Level of Automation	Characteristics
1. Radar AN/APS-506	The APS-506 is currently manually operated except for the capability to automatically track one target. No digital interface.	X-band pulse compression radar. PRF=500 Hz, RPM=6. Up to 500 messages/scan (when updated) Maximum range: 150 nm
2. ESM AN/ALR-502	The ALR-502 currently supplies digital estimates of emitter bearing and associated signal characteristics.	* The accuracy of the bearing and signal characteristics is classified. These numbers can be obtained from C-12-140-000/MB-z01 (p.4-36-1).
3. IFF AN/APX-502	The IFF sensor is currently totally unautomated. The IFF cannot process Mode C (altitude) information.	Unautomated, cannot process altitude information.
4. FLIR OR-5008/AA	Currently the FLIR device can be manually pointed or slaved to the radar bearing. There is no computer automated image processing associated with the FLIR. The display output is visually interpreted by the system operator.	Useful range 12-20 DM (ships), 12-14 DM (surface subs), 6-8 DM (sub. snorkel), 2-4 DM (periscope).
5. Camera KA-501A	No automation	(for database update), lateral coverage 144°
6. MAD	No automation	(vertically below flight path)
7. Link-11	The Link-11 interface is fully digital and is automated.	STANAG 5511 Compliant Data Link Information Format
8. ADP OL/5004/AYS	All track detection and update is done from manual inputs from the operator. There is a passive autodetect algorithm on the CP-140 although it is not used much because of false alarm rates.	The ADP processes the acoustic signals to determine signal characteristics.
9. SRS AN/ARS-501	The SRS is interfaced with the computer which determines the sonobuoy positions relative to the aircraft's geographic position and the target and updates buoy positions on the Multi-Purpose Display (MPD) tactical plots.	Update rate is one sonobuoy per second. A 4-element state vector and a 16-element covariance matrix is maintained for each sonobuoy through a Kalman filtering procedure.

4.2 Review of the Sensor Upgrades Currently Anticipated for the CP-140

The single most significant addition to the present sensor suite is a Synthetic Aperture (SA) capability that could be added to the AN/APS-506 search radar first upgraded with an associated digital scan converter that would permit automatic processing of the radar video signal in order to provide the contact input data to the fusion function. The addition of Electro-Optic devices (i.e., various types of TV) also remains a possibility.

Table VIII below summarizes the additional inputs to a sensor data fusion function provided by the proposed sensor suite upgrades for the Aurora and their intended use in addition to real-time sensor fusion. To this list, one should add a proposed upgrade to the ESM for better recognition of surface targets at longer range. Before any advanced data processing (such as ATDTI) is done, it is also necessary to upgrade the Radar, IFF and FLIR with digital scan converters in order to digitize the video signal. The MSDF inputs resulting from these upgrades would however be the same as in Table VI, thereby justifying their exclusion from Table VIII to prevent redundancy.

TABLE VIII

Proposed suite of sensors and their inputs to a data fusion function

Proposed Sensors	**Input to Multi-Sensor Data Fusion and furt use**
SAR	Range, bearing, platform ID, mapping, target size, video recording for post-flight analysis
Updated ADP and 99-channel SRS	ADP provides processing for up to 64 buoys SRS provides positioning
Electro-Optics (LLLTV, Gated TV)	Bearing, elevation, target attitude, mapping, video recording for post-flight analysis

4.3 Review of the Other Information Sources

Table IX below summarizes, in a non-exhaustive list, other information sources that can be used for data fusion. Although Link-11 can be viewed as a sensor (Table VI), in the sense that it provides already processed kinematic and identity sensor information (tracks), it can also be viewed as a source of non-sensor information data with an associated degree of belief to be ascertained by a local assessment of the quality and timeliness of the reports from other sources.

TABLE IX

List of other information sources

SOURCES	Type of Information
Link-11	- information on enemy forces (fixes, etc.) - information on own forces (PUs, aircraft, vessels, sonobuoys, etc.), and, - information of tactical importance (splash points, positions, text messages, etc.).
Visual Sighting	- confirmation by operator of platform ID (e.g., after a low altitude pass).
Encyclopaedic Data	- known shipping routes and air corridors, iceberg flow patterns, - special events that can lead to flotillas of similar ships, - preferred documented submarine routes.
Operator Input	- figure-of-merit of sensor reports.
Intelligence	- historical database of manoeuvres for certain platform types or ID. - satellite information (e.g., tracking of targets over several days by foreign government agencies). - prioritization of different platform databases of anticipated air and surface targets.
Environmental data	- local environment along the flight path.

Intelligence reports facilitate the identification of targets by allowing the fusion algorithm to look up a smaller portion of the database. The fusion function should allow for environmental data to affect both the positional uncertainty in the reported contact and/or track and the relative quality associated with a given information source, depending on its sensitivity to environmental conditions. It is reasonable to have the local environment along the flight path set the priorities and/or weights given to the different source reports.

Some operator input to the fusion function may be needed depending on how much automation can be achieved by sensor upgrades. Apart from this fact, operators are the most appropriate judges of the operational state of all sensors on board and should be able to assign a figure-of-merit to each sensor and provide it to the fusion function. During in-flight questioning of the aircraft's crew, this particular subject was mentioned as an invaluable addition that commanding officers would like to see implemented in the future.

5.0 SENSOR DATA FUSION PROCESS FOR THE CP-140

The objective of Multi-Sensor Data Fusion (MSDF) is to enhance the ability of the tactical crew to perform their missions. In carrying out the previously described missions, the Aurora crew is bombarded with information which must be correlated, fused and interpreted in order to arrive at some understanding of the tactical situation. At present, the fusion of this data is being manually performed by the operators. This chapter presents a discussion on how to provide automatic target tracking and identification through MSDF onboard a multi-sensor platform such as the CP-140.

5.1 Top-Level Functional Decomposition of the SDF Process

From our understanding of the CP-140 information sources, it seems advisable to distinguish three distinct entities to describe a top-level functional decomposition of the Sensor Data Fusion (SDF) process as shown in Figure 3:

- an Under Water Sensor Data Fusion (UWSDF) centre for surface and subsurface target tracking and identification;
- an Above Water Sensor Data Fusion (AWSDF) centre for air and surface target tracking and identification; and
- a common track database that insures the required communication between the fusion centres.

The wide gap between the requirements that each fusion centre has to meet, is mainly responsible for this type of architecture. This architecture allows different implementations for each of the MSDF functions within each of the fusion centres, since the problems addressed by each centre, as well as the types of data processed and the time scales involved, are quite different. Since there is bound to be some overlap in the targets for which each centre is mainly responsible, a common database insures the required communication between the fusion centres.

The UWSDF centre mainly deals with sonobuoy Doppler information which is subject to totally different clutter, false alarm rates, presence of ghosts, environmental conditions than those encounter in the AWSDF centre. It obviously involves different signal processing requirements and most likely different fusion algorithms. The state of the art in acoustic data processing is not at the same level as it is for the radar, ESM and FLIR (AWSDF) sensors.

Automatic detection and tracking is very difficult for acoustics sensors. Given the premise that surface surveillance should be the focus of our data fusion investigation, no emphasis will be put on the UWSDF centre in the rest of this report. Our sole recommendation would be to provide tactical decision aids to assist operators to output tracks and sometimes ID of underwater targets and large surface targets. For instance, an automatic acoustic sensor prediction capability has been suggested as a very useful decision aids (Ref. 12).

Assuming that maritime surveillance is the most frequent operational use of the CP-140, AWSDF is the area where the biggest payoff can be realized by the automation of the tracking and identification functions. The AWSDF process will fuse five sensors which are the radar, the IFF sensor, the ESM sensor, the FLIR sensor, and the Link 11 remote track source. Figure 4 shows these information sources that interface with the AWSDF process. The dotted boxes indicate the notional upgrades needed to provide the required information. AWSDF will also take inputs from the UWSDF and the navigation system. The UWSDF input will mainly consist of tracks for targets detected by sono-buoy sensors. This information will be used to correlate fused surface detections from radar, ESM, etc. with acoustic surface tracks.

The top-level functional decomposition of Figure 3 allows different implementations for each of the MSDF functions within the AWSDF centre. Three main data fusion functional architectures were already discussed in Chapter 2: Sensor-Level Fusion, Central-Level Fusion, and Hybrid Fusion. Here, we show an appropriate selection of these functional architectures to achieve target tracking and identification onboard the aircraft.

5.1.1 Recommended MSDF Architecture for Tracking

For the tracking aspect, based on the analysis of Refs.7 and 13 and considering the strengths and weaknesses of the CP-140 sensors, DREV is recommending a hybrid sensor fusion architecture. This is illustrated on Figure 5. The APS-506 radar, the IFF sensor, and the OR-5008/AA FLIR all have good resolution and accuracy and hence are ideal for central-level fusion. The ALR-502 ESM sensor has very poor resolution and accuracy in the one dimension (bearing) it measures. This fact makes central-level fusion inappropriate. Therefore the sensor-level fusion approach is selected in this case in order to allow an ESM track to first develop so that better data is available for the subsequent correlation process. The remaining sensors, Link 11 and acoustic sensors are suitable for sensor-level fusion since their outputs are already in track form and not in contact form.

5.1.2 Recommended MSDF Architecture for Identification

For the identification aspect, DREV is recommending a central-level fusion architecture to ultimately declare an ID from the fusion of the raw target features extracted by the SAR and FLIR sensors. For the identity information provided by the other sensors (ESM, IFF, Acoustics) or by non-organic sources (Link 11) already offering identity declarations as their output data, the sensor-level architecture is an appropriate approach. This architecture (Fig.5) can be adapted to include identity declarations inferred by operators as well as the ones deduced by non-organic systems.

5.1.3 The MSDF Track Data Base

Finally, the track database contains the resulting updates of the kinematic and identity information maintained for each track obtained after each new sensor report has been fused. A list of probable candidate platform IDs should be continuously updated, along with the belief in that ID. In addition, some other information about the track should be updated (such as possible allegiance, nationality, anticipated threat level, etc.) along with supports of these assertions (see Chapter 2, Table I, for a list of typical track information maintained in a track database).

5.2 AWSDF Tracking and Identification Algorithms for the CP-140

In this section, the functions constituting the AWSDF process and necessary to provide automatic target tracking and identification aboard the CP-140 are described, along with the selected appropriate algorithms. Figure 6 shows a detailed functional architecture capable of fusing the sensor data described in Figure 4. The processing blocks are:

- data alignment,
- data association,
- target state estimation,
- target identity information fusion,
- target kinematic behavior assessment (i.e. type of maneuver, etc.),
- track fusion,
- track management process (i.e. initiation, confirmation, deletion, etc.),
- cluster management process (i.e. merging, splitting, etc.),
- sensor management,
- sensor interface and control,
- track database.

The data flow between these functions is shown in Figure 6. For some functions, a preferred algorithm has emerged as a result of our trade-off study.

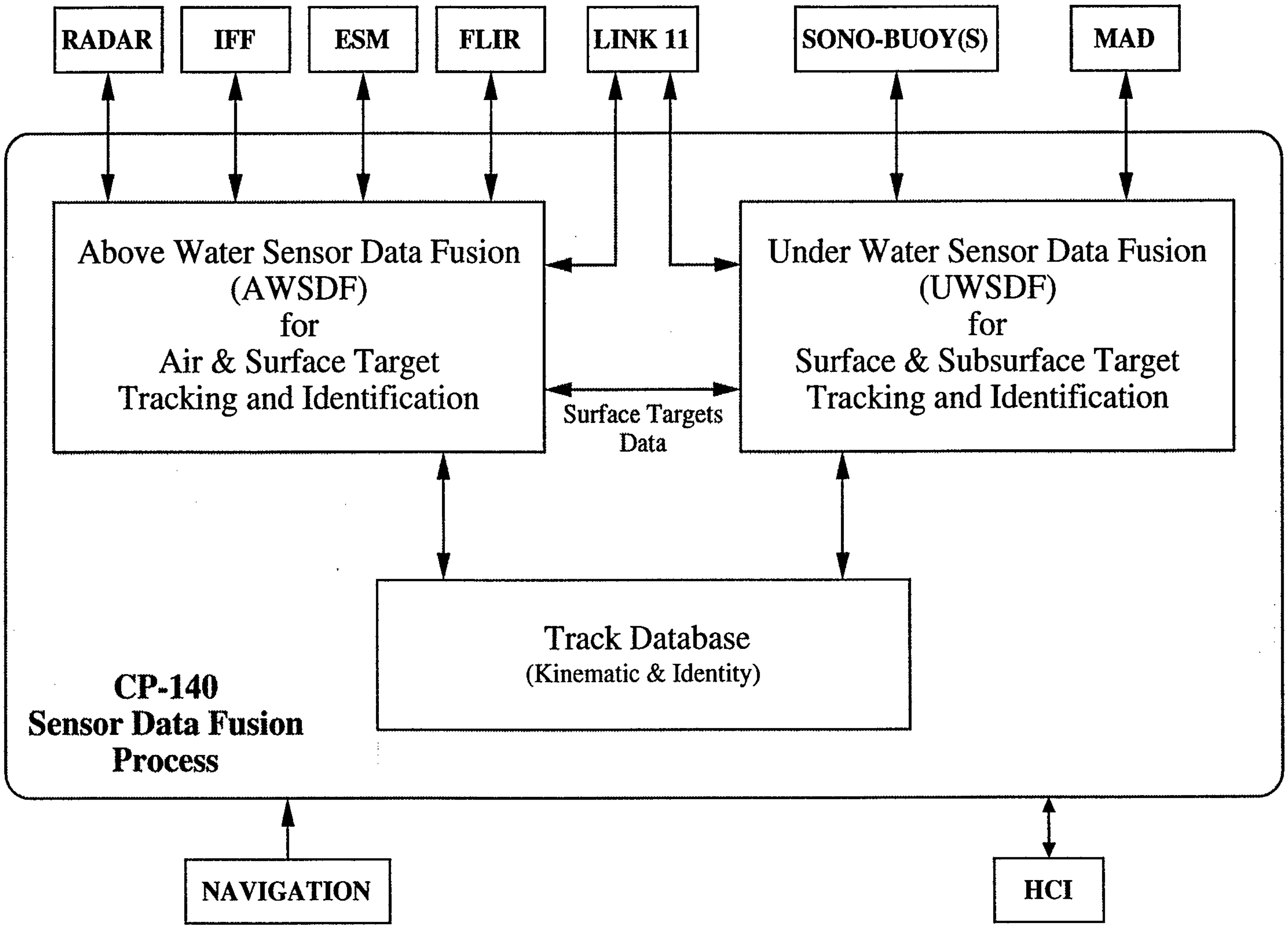

FIGURE 3- Top-level functional decomposition of the Sensor Data Fusion (SDF) process

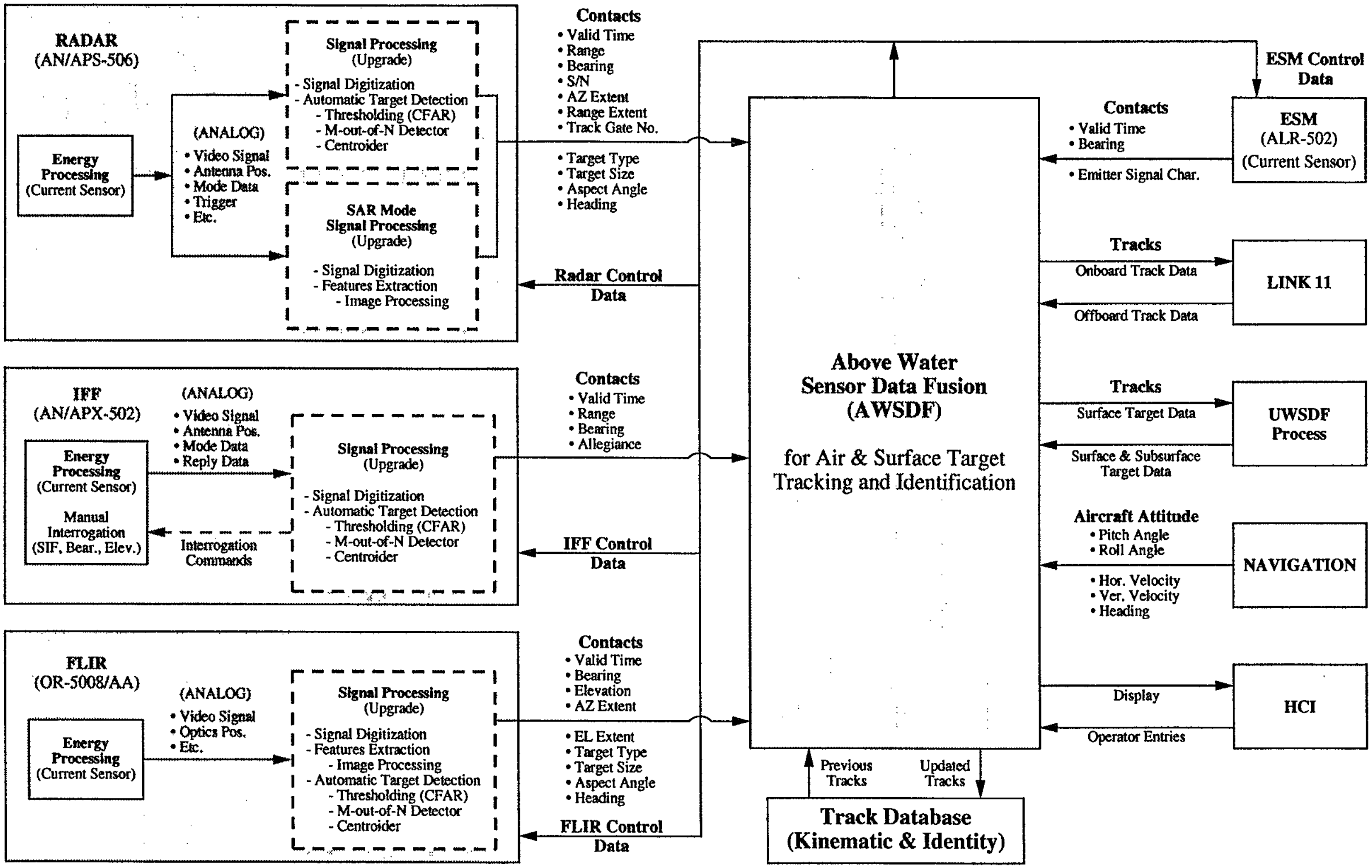

FIGURE 4 - Information sources interface with the Above Water Sensor Data Fusion (AWSDF) process

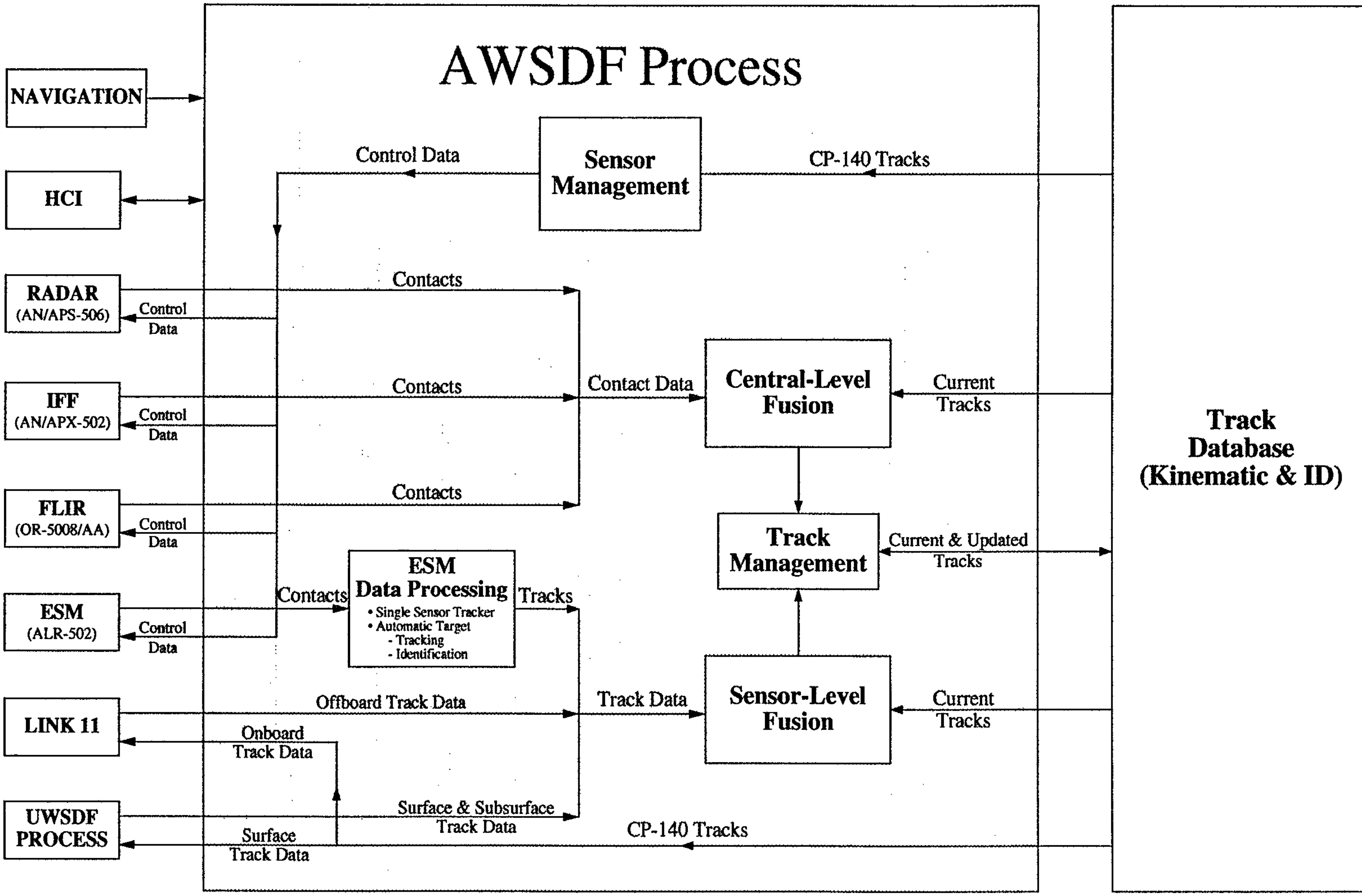

FIGURE 5 - Top-level sensor fusion architecture of the AWSDF process

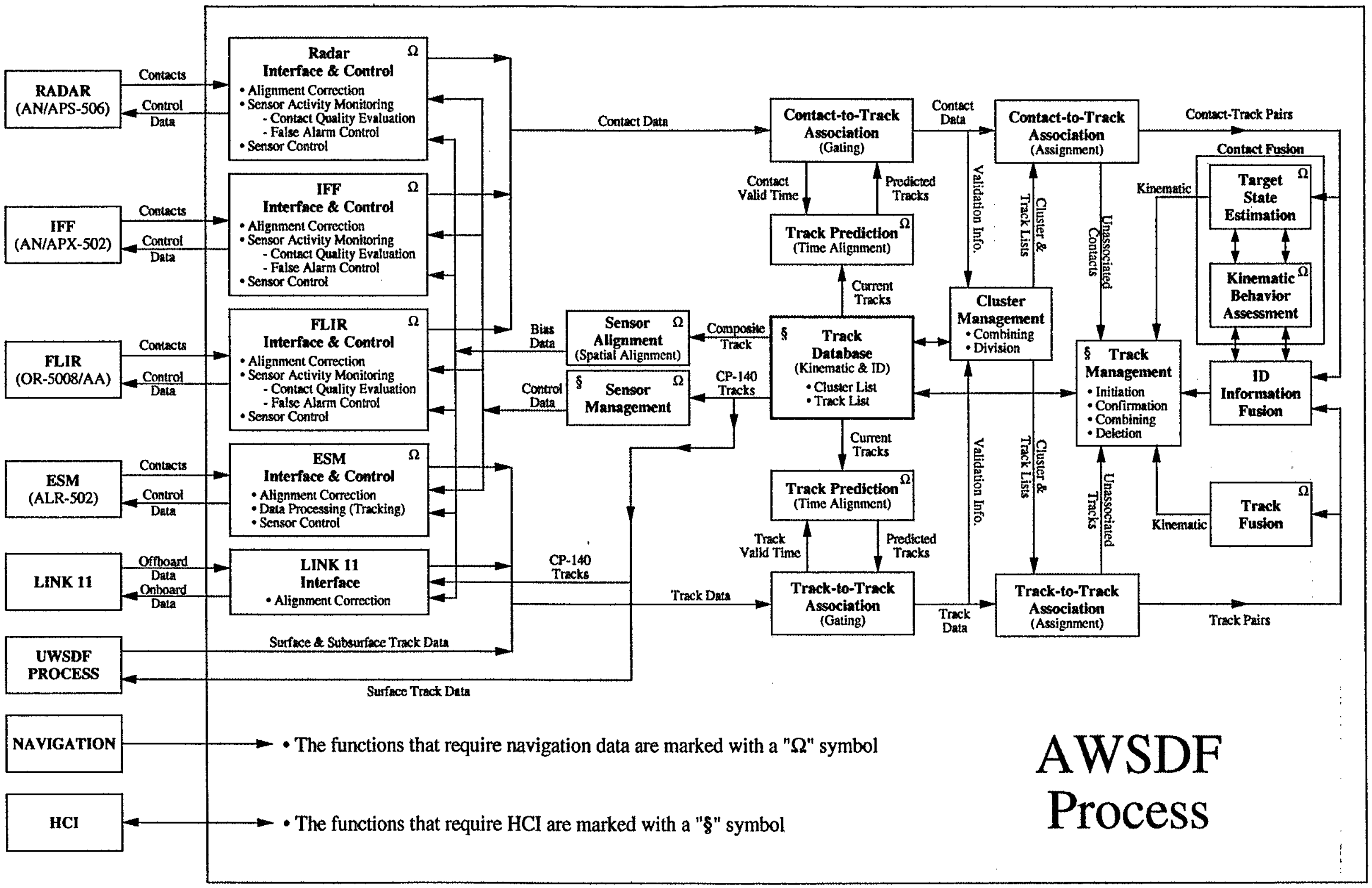

FIGURE 6 - Detailed functional decomposition of the AWSDF process

5.2.1 Sensor Interface and Management

An interface is required between the sensors and the data fusion functions. This interface is responsable of alignment correction and sensor post-processing functions for contact quality evaluation and reduction of false alarms before the sensor data is sent to the fusion process. The architecture also requires a sensor management function to provide feedback communication with each sensor. In general, this function provides such things as sensitivity adjustments, processing control, sensor cueing, ...etc.

5.2.2 Data Alignment

This process must perform both spatial and temporal alignment. Spatial alignment performs any necessary calculation to convert the contacts and tracks to the same geopositional frame of reference. Spatial alignment must take into account all possible sources of bias which could corrupt the alignment calculation. These sources can be local to the Aurora (vibration, sensor calibration errors, faulty mounting, false true north) and they can also originate on Participating Units (PUs) whose information must be aligned with the CP-140's. In Figure 6, the spatial alignment is shown in two steps: first, the estimation of the bias in the sensor alignment box and second, the actual correction of the incoming contacts or tracks in each of the sensor interface and control box.

An interesting data alignment scheme is proposed by Norden Systems (Ref.7). The first step in the alignment process is to identify tracks which are being updated by multiple sensors, have high track quality confidence, and are not maneuvering. This is done by looking at the sensor blip scan ratio, the track's covariance estimates, the track's promotion level, and the time since last update. The difference between the input contact or track and the reference track held by the sensor fusion system is calculated. This is done by time aligning the sensor fusion track to the contact time for radar, IFF, and ESM sensors and to the track valid time for the acoustic, Link 11, and ESM tracks. The difference is calculated in polar (range, bearing, and elevation) coordinates. The biases are accrued using a low pass filter so that noise is rejected while constant biases are accurately estimated.

The APS-506 radar is used as the reference sensor. The other sensors use the difference between their bias and the radar's bias as a feedback correction to the input measurements. The alignment system operates in a closed loop manner until all uncorrected biases achieve a zero mean. When alignment is enabled by the system operator a monitor function detects the remaining uncorrected bias and then turns off the alignment function when the remaining uncorrected bias reaches a small value. If alignment is disabled then the monitor function will issue an operator alert if the uncorrected biases reach an unacceptably high level. The bias corrections can be saved in Electrically Alterable Read Only Memory (EAROM) for use in future mission which may not have targets updated by multiple sensors (e.g., a scenario with a submerged submarine and a surface vessel).

5.2.3 Data Association

The function of the data association process is to determine if a new sensor contact or track originates from an existing track, or requires the creation of a new track, or is simply a false alarm. Its inputs are therefore new sensor data, and existing tracks which are time updated to the times of the input sensor data. In general data association can proceed either by considering data generated during a single scan or during multiple scans. In single scan mode, nearest neighbour algorithms (or variants thereof, such as the Jonger-Volgenant-Castanon (JVC) algorithm), maximum likelihood estimators and the Joint Probabilistic Data Association (JPDA) algorithms can be used. In multiple scan mode, one usually employs Multiple Hypothesis Tracking (MHT) algorithms that create a set of statistical hypotheses that must be tested in order to evaluate if the input data correlates with the tracks. The number of hypotheses must be maintained of manageable proportion for the available computing power. For practical computing cost reasons, the optimal algorithm consisting in keeping all MHT hypotheses is never considered.

Both Refs.7 and 13 recommended the MHT as an appropriate choice for the contact-to-track association process (FLIR, IFF, Radar). Because of the large target densities expected in many CP-140 missions and the possibility of imperfect removal of ocean clutter, the association method should cover many scans. For the track-to-track association process (ESM, LINK, ACOUSTICS), a simpler algorithm such as a nearest neighbour (JVC) would suffice because the tracks are well established. Ellipsoidal gating is recommended before applying MHT or JVC to prevent the very unlikely association.

5.2.4 Target State Estimation

This process mathematically refines the state of motion of a target track, by fusing the track's previous state vector (position, speed and covariance) with new associated sensor data. In some cases, the target behavior assessment process could suggest a specific model for target dynamics (constant acceleration, evasive maneuvers of a known type for the target ID). Every time a new contact arrives, the state estimation problem can be formulated either in batch mode or by the use of Kalman filters which process each new contact using only the information contained in the track's state vector and covariance matrix at the last contact time. Batch methods being much more computer intensive, the usual choice is to perform the state estimation through one or many Kalman filters and this is the preferred method. The output of the Kalman filter is an updated state vector and covariance matrix at the time of the fused contact.

5.2.5 Target Kinematic Behavior Assessment

This process supports the other functions, particularly the target state estimation, by suggesting target behavior models based on target characteristics such as speed, acceleration (previously observed or potential), direction of travel (noting potential encounters with geographical features or other targets) and manoeuvring capability (possibly by looking up database information).

5.2.6 Target Identity Information Fusion

This process uses fuzzy notions about relative physical characteristics of targets that can restrict the list of possible platforms uniquely satisfying those characteristics. Radar cross-sections (RCS), temperature, speeds and accelerations are characteristic physical attributes that can range from the "Very Large" to the "Very Small", through as many increments as one wishes, with flexible boundaries between the fuzzy classes. Attributes can generically be described as a fuzzy characteristic associated to a platform or a list of platforms. The fuzzyness can be the result of measurement error on a physical quantity, or the deliberate binning of that physical quantity into distinct finite classes, or the relative confidence on a detectable feature of the platform.

An estimate of *speed* can be provided by the target state estimation and *acceleration* can be obtained through the kinematic behavior assessment function. Target attitude can be assessed from the FLIRand, when fused with radar range information, can provide estimates of side and forward Radar Cross-Sections (RCS). Temperature of a target can be estimated from the FLIR image contrast relative to its surroundings (water or air). These physical characteristics can vary in time through either target behavior or increased accuracy of sensor measurement. For the purposes of determining platform ID, it is therefore often appropriate to provide only a rough (or fuzzy) classification of these physical quantities, such as Very Big, Big, Medium, Small and Very Small. To each class corresponds a list of known platforms possessing the given characteristic.

Some sensors suggest possible IDs in a more direct way. ESM can provide plausible *emitter* IDs which can be correlated with platform IDs. The acoustic signature can be processed by the Acoustic Data Processor (ADP) and provide candidate platform IDs. Finally, object recognition algorithms applied to imaging sensors, such as the SAR, can provide type identification (e.g. tanker, destroyer, frigate, etc.).

Ref.14 reviewed a representative sample of identity information fusion techniques: Bayesian inference, Dempster-Shafer theory, Altoft reasoning over attributes, and fuzzy logic. The net result of the comparison of these techniques is that if only one compromise method, valid for all missions, is to be chosen, then a truncated Dempster-Shafer algorithm would be the recommended choice. Ref.14 provides more details on this technique.

5.2.7 Track Management Process

For each existing track that is updated with new sensor data, the results of the State Estimation, Target Identity Information Fusion and Target Kinematics Behavior Assessment functions are sent to the Track Management (TM) function to update the track database. The TM function must also initiate a new track for each unassociated contact, confirm a track after several contacts are associated to that track and propose as candidates for deletion "bad" tracks for which no contacts have been reported for a long time.

5.2.8 Cluster Management Process

The purpose of clustering is to break a large problem into a set of smaller ones which are solved in parallel. A cluster is a set of tracks with common measurements. Initially, one cluster is set up for each confirmed target. Each new measurement is associated with a cluster if it falls in the validation region of any track from that cluster. A new cluster is set up for each unassociated measurement. Figure 7 shows an example of the clustering mechanism. If a measurement is associated with more than one cluster then those clusters are merged into a super cluster as shown on Figure 8. If tracks within a cluster separate (Figure 9) and have no more common measurements, then this cluster is subdivided accordingly into smaller clusters. The process of initiating, merging, splitting and deleting clusters is referred as cluster management.

5.3 Hardware Considerations

Recent trends in acquisitions of military computer hardware have shifted from specialized equipment to suitably ruggedized COTS equipment. Reduced Instruction Set Chips (RISC) running the UNIX operating system are a particularly popular choice. Presently, one of the most popular data bus standard is the VME bus. Norden used the Motorola MVME 167 68040 based single-board computer. Loral implemented the Data Fusion Demonstration Model (DFDM) on a Sun Sparc10 Workstation.

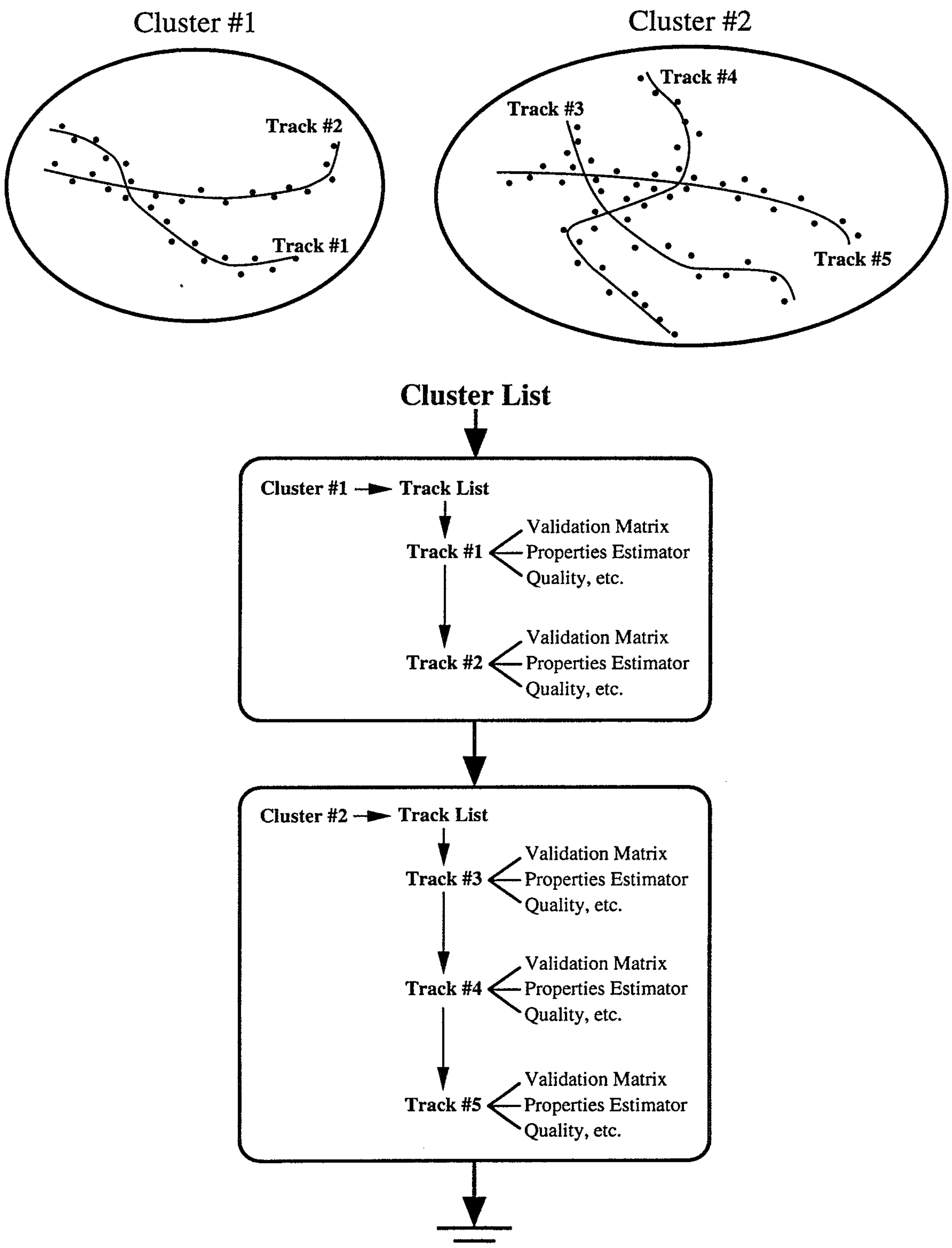

FIGURE 7- Clustering mechanism

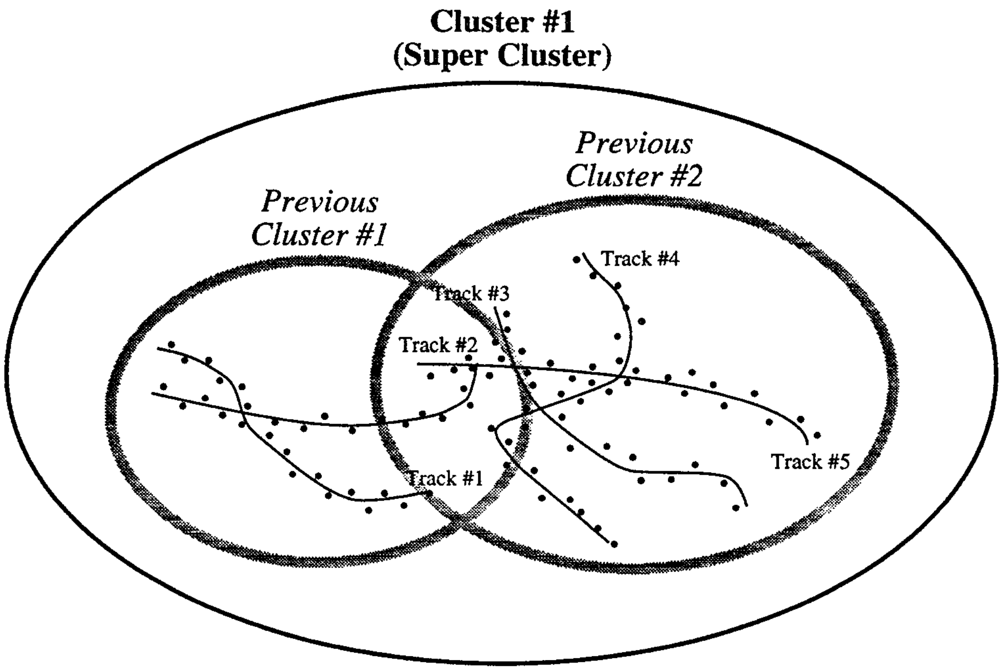

FIGURE 8 - Example of cluster merging

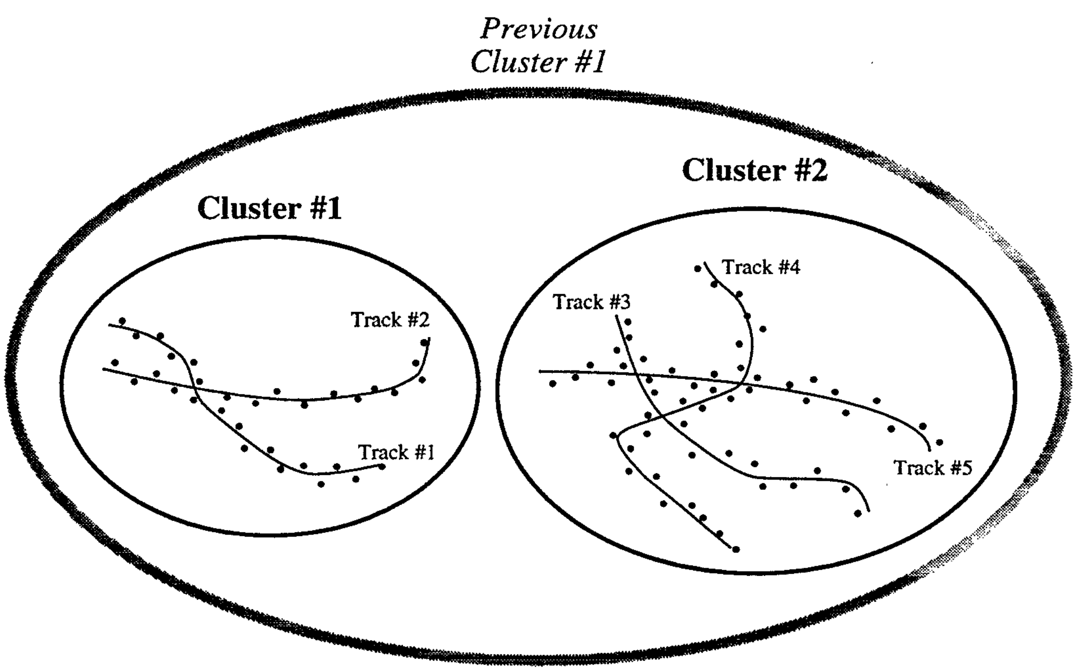

FIGURE 9 - Example of cluster splitting

6.0 EXPECTED PERFORMANCE IMPROVEMENTS

A study (Ref.15) has been conducted to assess the potential for enhancing the CP-140 crew efficiency by incorporating, among other technologies, data fusion. The data fusion and electronic library applications were found to offer the most potential to enhance the operator efficiency. This was attributed to the increased use of automation. Furthermore, it was emphasized that these technologies (data fusion, electronics libraries) might have a significant impact on overall mission effectiveness. Our intent in this chapter is not to investigate crew efficiency or crew size reduction potential which are beyond the scope of this report but to briefly summarize the potential benefits of MSDF in terms of operator efficiency and mission effectiveness.

6.1 Impact on Operator Efficiency

From a workload perspective, data fusion would generally be expected to result in reduced operator workload simply from the automation of functions that would otherwise be performed manually. During the last fifteen years, technological advancements have greatly increased sensor performance and capability to generate information. As a result however, the operators might be flooded by the volume, rate and complexity of the information provided by these sensors to a point where their ability to cope with that information may be exceeded. A key element to this information management problem is the ability to automatically combine or fuse data from the sensors.

At present, the fusion of this data is being *manually* performed by the operators through intercom communication, with little support from the Operational Program beyond that provided by the maintenance of the tactical database and the ability to control the various sensors "on-line" through the use of a common Operator-Machine Interface (OMI).

At the lowest level, the individual sensor operators must assimilate the information being presented to them from their sensor and, through adjustment of the sensor operation, they must resolve ambiguities in order to reach decisions on the nature and validity of the information being presented. For example, the radar operator must decide whether a particular radar return is a target or merely noise. In doing so, he or she is manually correlating sensor reports with known information on the mission environment. Based upon the results of the decision, the operator will either enter a contact into the tactical database or discard the information as irrelevant.

At the next level, the Mission Commander must integrate the inputs from the aircraft sensors, other crew members and friendly forces in order to arrive at as accurate as possible a representation of the tactical situation. Since this involves the manual correlation of tracks and additional sensor and non-sensor derived inputs, such as intelligence reports and communications with co-operating forces, assisted by the use of those decision aids which are available under the CP-140 Operational Program, it is an extremely demanding task which requires the full concentration of the Mission Commander.

Since virtually all of the data association and merging/combining (constituting the fusion process) which occurs during the course of an Aurora mission is presently performed manually, this activity contributes a significant portion of the overall operator workload. During periods of high activity, the operators may overlook valid information and arrive at an incomplete, or inaccurate, assessment of the tactical situation. As well, the varying levels of skill and experience among the operators may cause different individuals to reach different conclusions given the same information.

The operators function in the upgraded sensor fusion system will be very different from what the operator is doing in the presently equipped CP-140 aircraft. The operator must currently manually track virtually all of the targets which the aircraft has under surveillance. This is a very time consuming process. Experience in the U.S. Navy has shown that a good operator can handle no more than six manual tracks on a single sensor at any one time (Ref. 7).

This means with two operators doing manual tracking a maximum of 12 tracks can be handled by the aircraft at any one time on one sensor. If sensor fusion is desired on the targets of interest then the operators must operate more sensors and hence the number of tracks or the track quality will decline. If we assume that the two operators must handle three sensors (radar, IFF, FLIR or ESM) then the maximum number of tracks is 6 tracks/operator * 2 operators /3 sensors = 4 fully fused sensor tracks.

This arithmetic changes drastically when an automated sensor fusion system is implemented on the aircraft. The number of tracks which can be simultaneously tracked is nearly limitless (greater than 500). The operators duties now become one of track and sensor management. The operator will be presented with a clear track picture with all targets held by the sensor fusion system being clearly displayed.

The operators' job will be to insure that the sensors are operating properly and to make judgment calls about track identity and intentions. He will have a much more complete data base on which he can base his judgments.

6.2 Impact on Mission Effectiveness

Table X below summarizes the benefits of MSDF which impact on mission effectiveness. Here are some examples of how those MSDF benefits can be specifically related to CP-140. For instance, the APS-506 radar which is the most important sensor on the aircraft for marine surveillance missions will allow the automated surveillance of large areas of the ocean if it is properly equipped. If the aircraft is at an altitude of 25,000 feet an area of about 79,000 square miles is covered by the radar. At an altitude of 10,000 feet an area of 32,000 square miles is covered with antenna in horizon sweep mode. These areas are far too large for manual target detection and tracking, unless the radar threshold is set high enough that only the largest and closest targets are displayed for manual tracking.

TABLE X

Potential MSDF Benefits which impact on Mission Effectiveness

MSDF Benefits	Explanations
Robust Operational Performance	One sensor can contribute information while others are unavailable, denied (jammed), or lack coverage of a target/event
Extended Spatial Coverage	One sensor can look where another cannot
Extended Temporal Coverage	One sensor can detect/measure a target/event when others cannot.
Increased Confidence	One or more sensors can confirm the same target/event
Reduced Ambiguity	Joint information from multiple sensors reduces the set of hypotheses about the target/event.
Improved Detection	Effective integration of multiple measurements of the target/event increases the assurance of its detection.
Enhanced Spatial Resolution	Multiple sensors can geometrically form a synthetic aperture capable of greater resolution than a single sensor can form.
Improved System Reliability	Multiple sensor suites have an inherent redundancy
Increased Dimensionality	A system employing different sensors to measure various portions of the electromagnetic spectrum is less vulnerable to disruption by enemy action or natural phenomena.

The process of manually tracking a target is also very time consuming and error prone. The operator must first discern the targets video on the PPI or B scan display. He must then offset the radar video and change radar scale until only the target he is trying to track is visible on the display. If the operator keeps the radar on maximum range scale then he will have huge tracking errors. If a 12" radar PPI display is used and the radar is in a 150 mile mode then an error of .01 inches corresponds to a radar measurement error of 1,500 feet. These error become proportionately worse if a smaller display is used.

It is impossible to determine target speed or heading with errors of the magnitude stated above. Therefore the time consuming process of radar offset and range scale change must be used to determine the target's direction and speed. While the operator is updating one track the rest of the surveillance volume is unobserved because the operator is concentrating only on the track being updated or tracks in the immediate vicinity of the track he is updating.

Detection/Track initiation is much quicker with sensor fusion. One reason is the mutual support provided by the various sensors that reduces the number of "holes" in the data due to sensor fades. Secondly the aggregate scan period of the suite of sensors is significantly less than the fastest sensor. For example if the APS-506 radar is in a 10 second scan mode and the FLIR sensor is scanning the same area at the rate of once every 10 seconds then the average update rate for a target being seen by both radar and the FLIR is once every 5 seconds.

Track accuracy is better because tracks are updated by all sensors rather than having individual tracks on each sensor and selecting the "best" track. Better track continuity is achieved since the probability that all sensors are experiencing a fade at the same point is small. The overall *resolution* of the sensor fusion system can be as good as the best sensor. For example if the FLIR has a bearing resolution of 0.01° then the system resolution will approach the FLIR resolution.

7.0 RECOMMENDED IMPLEMENTATION PLAN

This chapter describes the way DREV sees the implementation of an Automatic Target Detection, Tracking and Identification (ATDTI) capability for the CP-140. A large amount of hardware and software required to realize this ATDTI currently exists as Commercial-Off-The-Shelf (COTS) and Government-Off-The-Shelf (GOTS) items. Some modifications to the existing systems will have to be made to tailor them for the CP-140 airborne surveillance mission.

The automation can be achieved in a number of different ways, and depending on the level and the sophistication of this automation, the performance gains for different missions will be different. It is important to identify the cost/performance trade-offs for implementing increasing levels of sophistication. Also, based on the priorities of different types of missions, the implementation of the automation can be prioritised to start from automating the highest priority missions and incrementally add automation in other missions according to their priority. Currently, maritime surveillance seems to be the most frequent operational use of the aircraft.

One could first do ATDTI with each single sensor individually, and only subsequently do sensor fusion. However, as already discussed in Chapter 2, this is not the optimal way of doing automated surveillance with a multiple sensor system since one limits the fusion to be at the track level as opposed to fusion at the contact level which is the optimal approach. Moreover, implementing ATDTI for each sensor requires to develop capabilities (such as track association, identification and track management) which are required anyway for fusion both at the track level and at the contact level. Hence, the most efficient design would be to develop these capabilities to achieve optimal sensor fusion at the contact level when appropriate.

The proposed incremental approach shown on Fig. 10 is a way to implement an ATDTI capability on the CP-140 by proceeding with recoverable steps where different level of fusion sophistication can be progressively implemented. A three step approach is put forward based on the availability of the technology and the actual status of the sensors on the aircraft. The three step process can also be viewed as development phases yielding one single deliverable system.

7.1 STEP 1: Baseline ATDTI with Radar, ESM, Link and IFF

Considering the current status of the sensors on the CP-140 (Chapter 4), STEP 1 represents a minimum that has to be implemented to provide an efficient ATDTI capability aboard the aircraft. This is an optimal, low risk implementation that would require relatively low effort since most of the required hardware and software currently exists as COTS items. Table XI below gives a list of the necessary functions to realize STEP 1, as well as a description of each function item and the potential modifications required on the COTS/GOTS items that could eventually be used for its implementation.

In this initial implementation of the ATDTI for the CP-140, the radar and IFF sensors, first upgraded with off-the-shelf cards to perform Automatic Target Detection (ATD), provide contacts to the Track Management System (TMS) developed by Westhinghouse Norden Systems. Fig. 11 illustrates the radar and IFF initial upgrades required to automatically provide contacts to the TMS. The first four items of Table XI describe what is needed to implement these initial sensor upgrades.

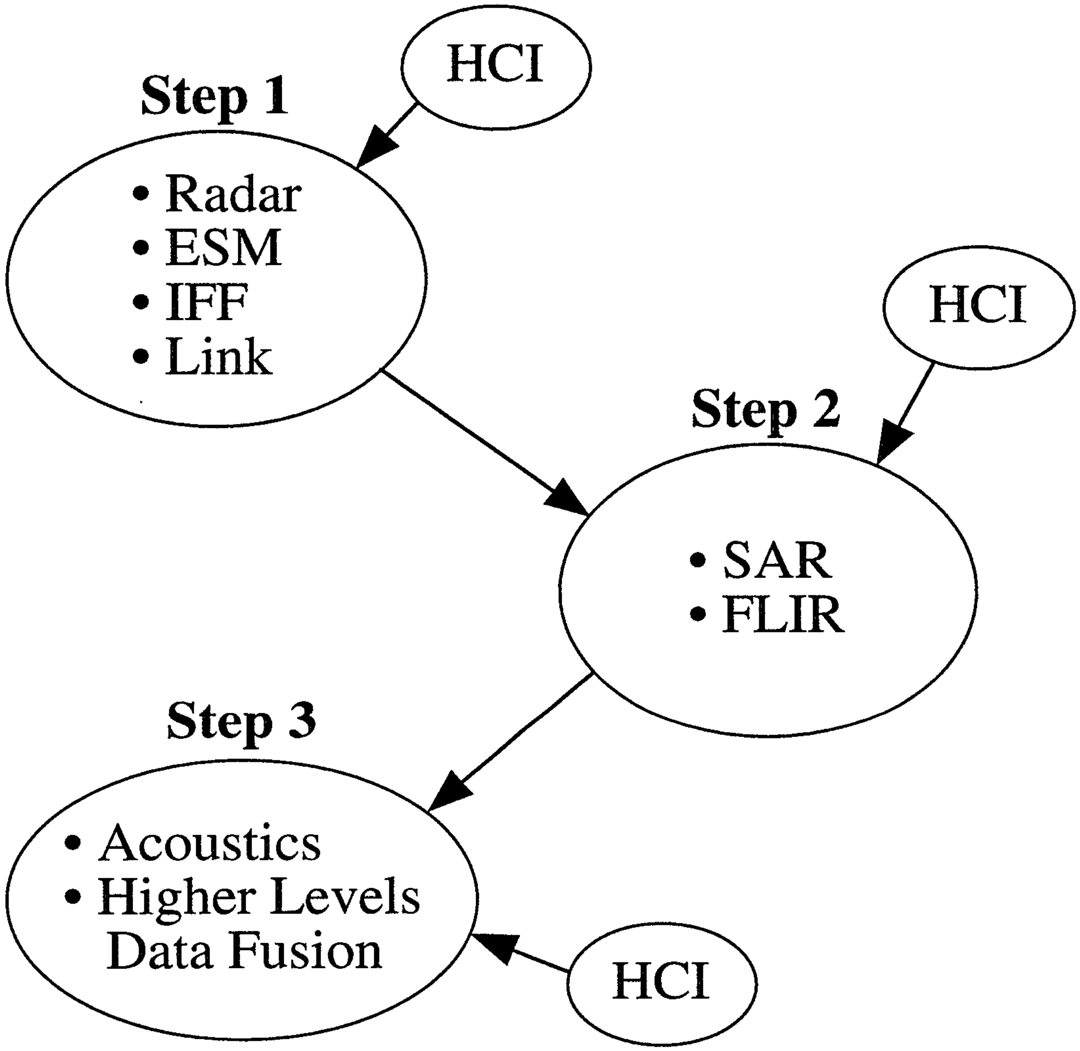

FIGURE 10 - Recoverable steps of the incremental approach recommended by DREV to implement sensor data fusion on the CP-140

TABLE XI

STEP 1: Baseline ATDTI with Radar, ESM, IFF and LINK

Function	Function Item Description	GOTS/COTS Item	Modifications Required
Radar Signal Digitization	The radar Adaptive Video Processor (AVP) converts APS-506 video to digital format.	COTS - Norden has a shipborne AVP and other companies may have some as well.	Norden's AVP would need modification to operate with APS-506 radar parameters and in an airborne environment.
Radar Automatic Target Detection	- Thresholding (CFAR) - M-out-of-N Detector - Radar Centroiding	COTS - This software exists in the Norden AVP.	The software would have to be "tuned" to the APS-506 radar.
IFF Signal Digitization	The IFF Beacon Video Processor (BVP) converts IFF video to digital format.	COTS - Hazeltine, Telephonics.	These companies have shipborne IFF BVP systems. They may have airborne IFF BVP systems.
IFF Automatic Target Detection	The IFF Beacon Video Processor (BVP) provides the digital contacts.	COTS - Hazeltine, Telephonics.	These companies have shipborne IFF BVP systems. They may have airborne IFF BVP systems.
Sensor Interface and Management	- Alignment Correction - Link Gridlock - Sensor Activity Monitoring - False alarm reduction - Contacts Quality Evaluatio - Sensor control	COTS - This software exists in the Norden TMS. -Adaptive Correlator - Gridlock function exists for the NWS.	The software currently only handles contact alignment. The track alignment would have to be added for the LINK.
Contact-to-Track Association	- This function is needed for radar and IFF contacts. - Gating - Assignment	COTS - This software exists in the Norden TMS	This function would require little or no modification for the CP-140 application.
Target State Estimation & Kinematic Behavior Assessment	- These functions perform contact fusion and state estimation	COTS - This software exists in the Norden TMS	This function would require little or no modification for the CP-140 application.

TABLE XI (Continued)

STEP 1: Baseline ATDTI with Radar, ESM, IFF and LINK

Function	**Function Item Description**	**GOTS/COTS Item**	**Modifications Required**
Track Management	- This function performs tracks initiation, deletion and confirmation.	COTS - This software exists in the Norden TMS	This function would require some tuning for the CP-140 application.
Cluster Management	- This function performs cluster initiation, splitting and merging.	GOTS - DREV: CASE_ATTI * available in litterature	This function has to be developed. Not expected to be a big effort.
ESM Tracking	- Automatic tracking for the ESM	COTS: Partially developed by Norden.	An ESM tracker has to be developed. Most of new ESM systems have this capability.
Track-to-Track Association	- Needed for the correlation of the ESM and data link tracks with the CP-140 composite tracks.	COTS: A JVC algorithm exists at Loral.	The JVC algorithm at Loral must be verified for the CP-140 application.
Track Fusion	- Needed for the fusion of ESM, LINK and CP-140 composite tracks	GOTS - DREV: CASE_ATTI * available in litterature	This function has to be developed. Not expected to be a big effort.
Identity Information Fusion	This function is used to automatically declare the ID from ESM, IFF, LINK and kinematic data.	COTS- This software exists in the Loral DFDM demonstrator	This function would require some tuning for the CP-140 application.
Sensor Fusion System Operator Display	- Needed to present a coherent picture of the entire volume of space surrounding the CP-140	COTS - Norden has a display for the TMS	Unknown

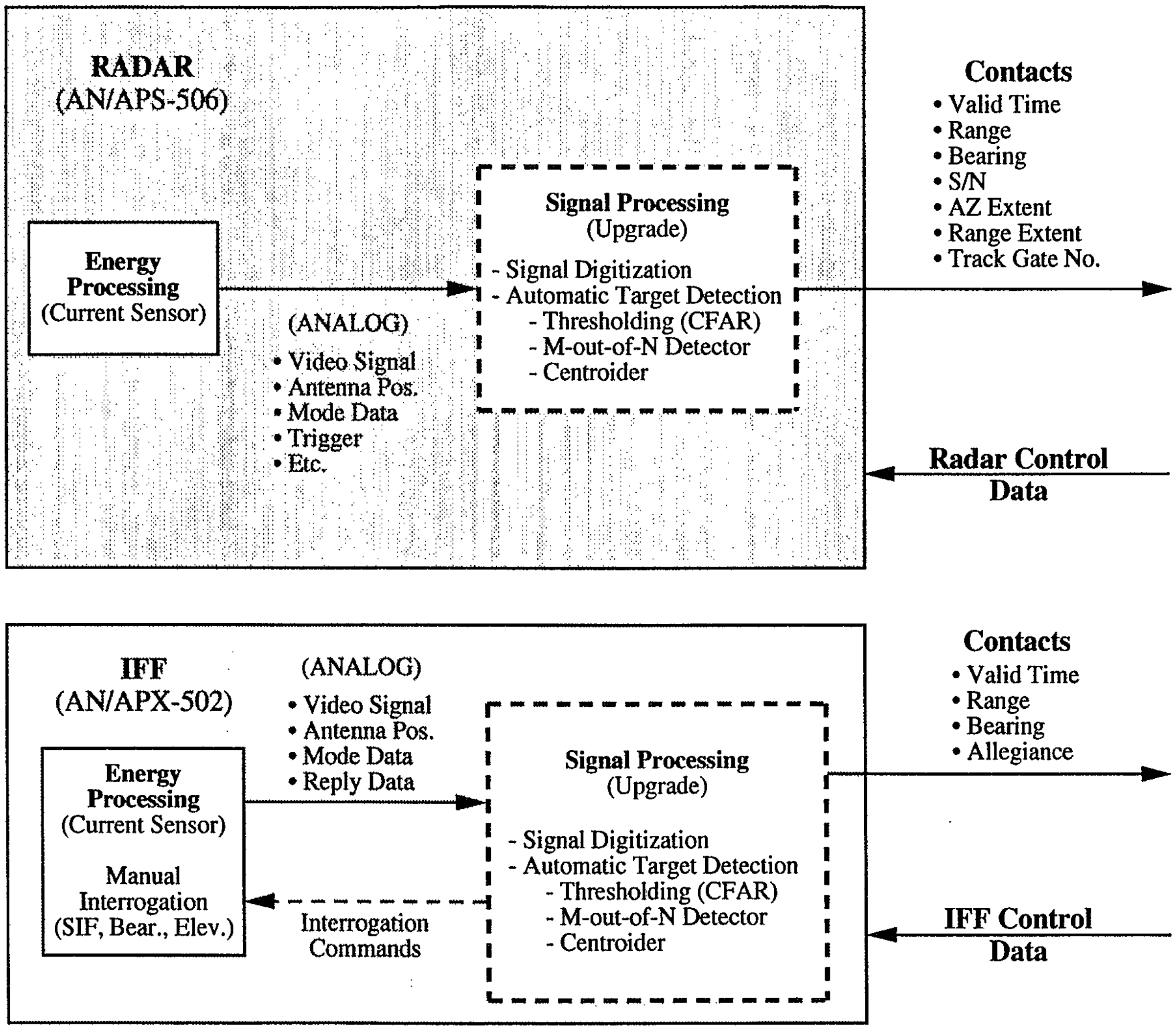

FIGURE 11 - Radar and IFF initial upgrades required for step 1

The TMS will achieve automatic tracking using both radar and IFF contacts. This software is capable of performing the necessary functions (alignment, association, target state estimation, track management, etc.) to fuse radar and IFF contacts and generate tracks.

The ESM sensor currently has a complete digital interface which could be used without modification to provide bearing contacts to an eventual ESM tracker that needs to be developed. This ESM tracker development is not a big effort since most of the modern ESM systems have a tracker. Link 11 is providing its data in track form and the major problem with using this data is to properly align the CP-140's coordinate system to the link coordinate system. Gridlock techniques used to solve this problem for the North Warning System (NWS) could be used for the CP-140. GPS will also certainly help to solve this problem asuming the other platforms use GPS as well.. A track-to-track association algorithm is needed for the correlation of the ESM and Link-11 tracks with the CP-140 composite tracks. Loral has developed a JVC algorithm for the DFDM project (Ref. 16) that may fulfill this requirement. Finally a track fusion function is required to fuse ESM, Link and CP-140 composite tracks.

With very minimal risk, ESM ID information, IFF responses, link data and kinematic data can be processed by a truncated DS evidential theory algorithm in the identity information fusion subprocess of AWSDF (as Loral successfully did in the CPF DFDM (Ref. 16)). This function is used to automatically declare the target ID from ESM, IFF, LINK and kinematic data.

STEP 1 would provide automation for target detection and tracking as well as automatic target identification in most of the surface and air surveillance and patrol missions. With a minimum effort, very good ATDTI can be achieved by just implementing this step.

7.2 STEP 2: Advanced ATDTI with the SAR and the FLIR

STEP 2 involves medium risk technology and requires more effort than STEP 1. This step can potentially provide great benefits for both tracking and identification since the radar and the FLIR are the two most important CP-140 sensors for maritime surveillance. The fusion of radar contacts with the FLIR's digitized imaging data will achieve short range identification while the capability for long range target identification will be provided by the SAR.

Table XII lists the necessary function items to provide the advanced ATDTI capability on the CP-140. Figure 12 shows what modifications are required on the actual radar and FLIR to provide the necessary digital information to the AWSDF system. There are digitizers on the market, referenced as frame grabers, that convert video image to digital format. A SAR mode needs to be fitted to the CP-140 APS-506 radar. A contract has been recently awarded to Loral and its partners to achieve that.

Current status of the object recognition technology and real-time constraints dictate the use of basic image processing software for feature extraction in order to keep the risk as medium. More sophisticated feature extraction techniques that are still considered as laboratory concepts should only be addressed in STEP 3. The actual FLIR on the CP-140 is manually operated with no computer automated image processing. It might be possible to use the same feature extraction software for both the SAR and the FLIR.

7.3 STEP 3: Full SDF System Implementation

With the implementation of STEP 1 and STEP 2, the Above Water Sensor Data Fusion (AWSDF) centre is realized. Assuming that the role of the aircraft is largely for maritime surveillance, this implementation of level-1 data fusion with the above water sensors would be sufficient to provide the ATDTI capability to the CP-140. However, priorities may rapidly change and this may necessitate a full Sensor Data Fusion (SDF) system implementation involving acoustics and higher levels of data fusion (i.e., levels 2, 3, and 4 (see Chapter 2)). This full SDF system implementation is referred to as STEP 3 and is described in Table XIII.

TABLE XII

STEP 2: Advanced ATDTI with SAR and FLIR

Function	Function Item Description	GOTS/COTS Item	Modifications Required
STEP 1	see STEP 1 Table		Parts of the software may require some modifications with the addition of SAR and FLIR.
SAR Upgrade	- Automatic Target Detection and Features Extraction	COTS & GOTS: Loral & DREO have the necessary software & hardware	N/A
FLIR Video Processor	The FLIR Video Processor converts FLIR video into digital format.	COTS: Frame Graber	Unknown but expected to be little.
FLIR Upgrade	- Automatic Target Detection - Thresholding, centroiding - Automatic Features Extraction	COTS: Basic Image Processing Software	Verify if the software developed for the SAR might be used for the FLIR (Feature extraction)
Identity Information Fusion	- Needed for the fusion of identity information from SAR, FLIR, IFF, ESM, LINK and kinematic data.	COTS- This software exists in the Loral DFDM demonstrator	This function would require some modifications to accept features from FLIR and SAR
Sensor Fusion System Operator Display	- Needed to present a coherent picture of the entire volume of space surrounding the CP-140	COTS - Norden has a display for the TMS	Unknown

STEP 3 involves high risk technology and could require extensive effort. To mitigate the risk, a proof-of-concept phase will be needed as well as further research in some areas where very sophisticated algorithms have to be implemented. We have chosen to separate this step from the first two since some technology issues still have to mature.

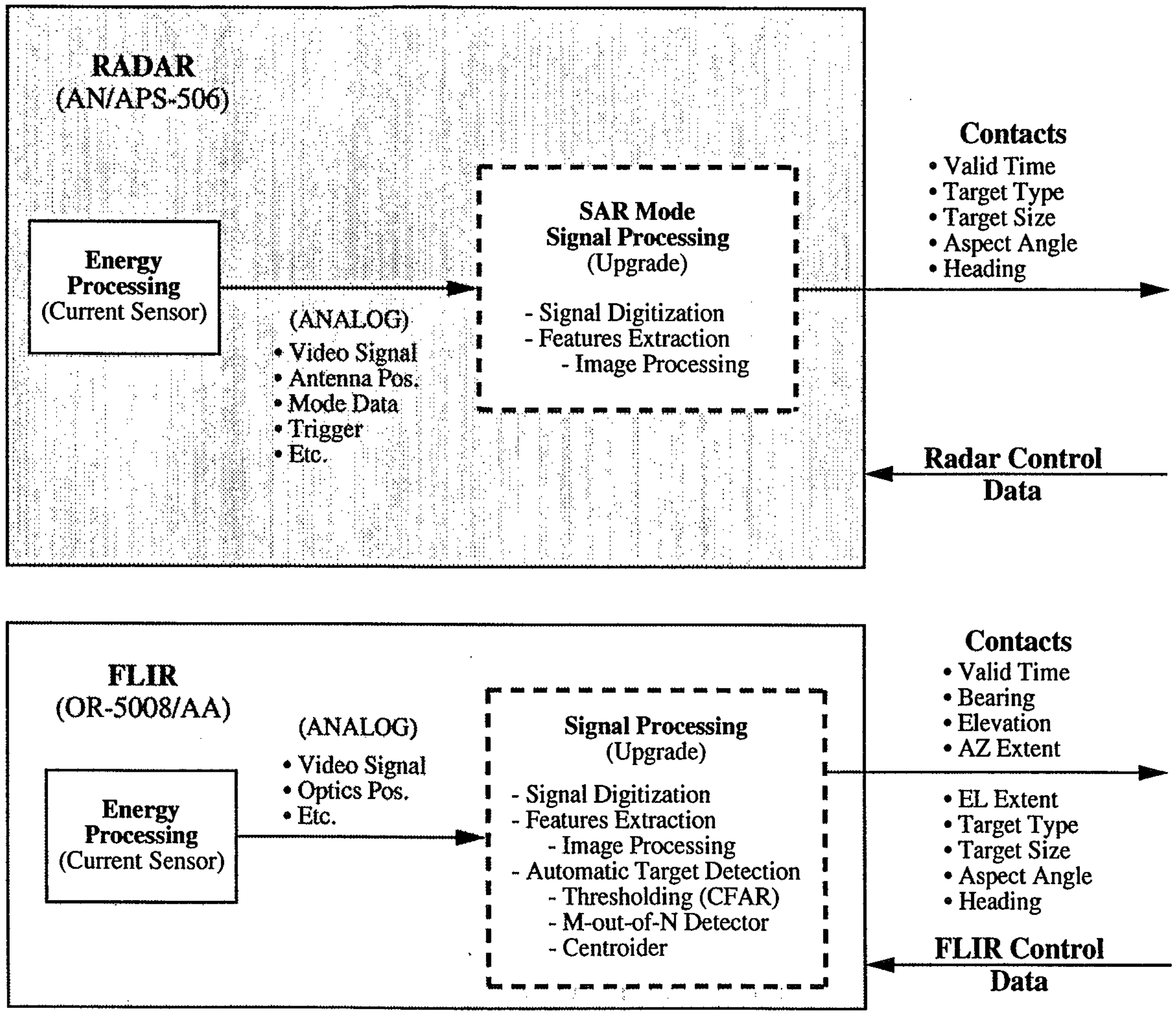

FIGURE 12 - Radar and FLIR upgrades for step 2

Currently, feature extraction techniques for real-time application mostly rely on very basic image processing software. More sophisticated feature extraction and object recognition techniques have to be developed. In this respect, the ongoing Defence Industrial Research (DIR) project entitled "Context-Sensitive Data Fusion" (Ref. 17) awarded to MacDonald Dettwiler will certainly deliver useful tools for features extraction in terms of image fusion algorithms, visualization techniques and merging of imagery with tactical information. Another relevant ongoing activity, is the Loral/Queens NSERC grant project on the fusion of information from imaging and non-imaging sensors. This project will develop MSDF algorithms for distant airborne detection, tracking and recognition of objects for ocean surveillance.

The automatic analysis of the acoustic signal is another extremely challenging problem often involving numeric, AI and neural networks approaches. These approaches process and fuse multiple signals from multiple sensors to derive passive bearings, fixes, tracks and platform attribute data. The data on surface and subsurface targets, available to the automatic sonar processors through the common MSDF database, will help decide on the sonobuoy deployment pattern, and will help localise the target much sooner.

The availability of COTS and GOTS components for the upgrade of the acoustic system is somewhat more limited than for the non-acoustic sensors. DREA is working on an experimental Acoustic Sensor Prediction Capability. Currently, Loral (US) has an R&D project supported by DoD to study various techniques of acoustic signal processing (decluttering, feature extraction) which could be applied in the CP-140 case. Westinghouse Norden systems is currently doing work for the U.S. Navy under the WLY-1 program. Acoustic data has been digitally recorded during actual sea trials and playback into a prototype system that performs automatic detection and tracking functions. This prototype system has the demonstrated capability to maintain tracks on over 1000 frequency lines and has the storage capability to maintain tracks on up to 8000 lines simultaneously.

The implementation of higher-level data fusion for both the AWSDF and the UWSDF requires substantial research effort prior to proceeding to any implementation.

No COTS or GOTS items are really available to achieve these levels of fusion, except perhaps the decision aid tools that are currently being developed under the MDA DIRP and a NSERC project on adaptive planning with Loral/DREV and the University of Montreal.

TABLE XIII

STEP 3: Full SDF System Implementation

Function	Function Item Description	GOTS/COTS Item	Modifications Required
STEP 2 (refinements)	see STEP 2 Table - More sophisticated feature extraction techniques - Image fusion (SAR & FLIR)	- MDA DIRP on Context-Sensitive Data Fusion - Loral/Queens NSERC project	Adjustments might be required.
Acoustic ATDTI	- This function will provide acoustic track position, velocity accuracy and classification data from sunoboys.	GOTS & COTS - Software exists at Loral (US), Westinghouse (US).	- Unknown
UWSDF	- Tactical Decision Aids (Automatic Acoustic Sensor Prediction Capability (ASPC)) - Acoustics Sensor Fusion	GOTS - DREA is working on tactical decision aids for integrated active/passive processing	A demonstration system has been flown in an Aurora
Level-2-3 Data Fusion	- Situation Assessment (time, space) and Threat Assessment - Pattern recognition (e.g., flotilla deployment)..	COTS: MDA DIRP	- Proof-of-concept is required.
Level-4 Data Fusion	- Resource and Sensor management: planning and decision support functions to allocate, schedule and select the best course of action in support of the mission.	GOTS: DREV has some algorithms for adaptive planning. Loral is starting some work on that.	- Proof-of-concept is required.
Advanced HCI	- Needed to present full data fusion capabilities.	Unknown	- Proof-of-concept is required.

7.4 Final Considerations on the Recommended Implementation Plan

The purpose of the implementation plan recommended in this chapter was to clarify what is currently available and ready to be implemented at low cost and risk, what could be implemented at medium cost and finally what is very risky and needs substantial effort. This was the motivation underlying the three step approach put forward. In fact, it is premature at this moment to undertake an implementation phase, to acquire or manufacture the system described in this report. We strongly suggest to first conduct a low cost Project Definition Study (PDS) sub-phase. The purpose of this PDS sub-phase would be to refine the approach proposed in this report by providing its complete costing and a better assessment of the suggested implementation steps in terms of time, risk and complexity. This would provide to ALEP the basis for the SOW for the more costly implementation phase.

The PDS sub-phase shall be partionned into the following tasks:

1) review the DREV/NORDEN/LORAL documents;

2) analyse and refine the steps proposed by DREV;

3) detail the tracking and identification processes needed to implement STEP1;

- identify the refinements required for the already developed algorithms;
- identify the algorithms that needs to be developed;
- maximize the use of COTS/GOTS and identify the missing parts;
- identify the HCI requirements;
- provide a design diagram to implement STEP1;
- evaluate the risk and cost the efforts.

4) detail the processes to implement STEP2 and STEP3;

- identify the refinements required for the already developed algorithms;

- identify the algorithms that needs to be developed;
- maximize the use of COTS/GOTS and identify the missing parts;
- identify the HCI requirements;
- evaluate the risk and cost the efforts;

5) conduct a trade-off study between the steps in terms of efforts and expected benefits;

6) evaluate the first prototype development cost for each step individually;

7) evaluate the subsequent implementation cost per aircraft for the each step individually.

8.0 CONCLUSION

The purpose of the project discussed in this document was to:

1. study the feasibility of implementing data fusion aboard CP-140;
2. clarify the terminology and specify the data fusion capabilities;
3. based on the Canadian Patrol Frigate (CPF) expertise built up at Loral, examine what could be transported to the CP-140 aircraft;
4. based on Westinghouse Norden Systems fielded data fusion technology to the USN ships and their proposal to the P3 aircraft, examine what could be transported to the CP-140 aircraft;
5. develop sensible requirements for the CP-140 aircraft based on the results of this task; and
6. ensure the feasibility of the requirements imposed on the CP-140 aircraft.

The scope of the study was imposed to maritime surveillance with the non-acoustic sensors. The acoustics perspective was seen too demanding. This limitation in scope was not to re-prioritize the CP-140 missions nor to investigate crew efficiency or crew size reduction potential. It provided better assessment of the benefits of data fusion against those missions.

This report presented the final results on the feasibility and usefulness of data fusion for the CP-140 Aurora maritime patrol aircraft. Relevant sensor fusion concepts and terminology have been defined along with a description of the CP-140 operational environment and information sources. An analysis of applicable sensor fusion processes has been presented followed by a discussion on the expected performance improvements. Finally, a three step incremental approach has been proposed with recoverable steps where different level of fusion sophistication can be implemented based on the availability of the technology and the actual status of the sensors on the aircraft. The three step process can be viewed as development phases yielding one single deliverable system.

It was judged premature at this moment to undertake an implementation phase, to acquire or manufacture the system described in this report. It was suggested to first conduct a low cost Project Definition Study (PDS) sub-phase. The purpose of this PDS sub-phase would be to refine the approach proposed in this report by providing its complete costing and a better assessment of the suggested implementation steps in terms of time, risk and complexity. This would provide to ALEP the basis for the SOW for the more costly implementation phase.

The results presented in this report will be used to derive reasonable and prioritized requirements for the CP-140. The report will be provided as reference documentation to the ALEP definition contractor as supporting data. The definition contractor will then make its proposal for implementation.

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5. DATE OF PUBLICATION (month and year)	6a. NO. OF PAGES	6b. NO. OF REFERENCES
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7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. Give the inclusive dates when a specific reporting period is covered.)

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0288911A	N/A

10a. ORIGINATOR'S DOCUMENT NUMBER	10b. OTHER DOCUMENT NOS.
DREV R-9524	N/A

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